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Sustainable energy in Africa: A comprehensive data and policies review

Stefano Mandelli *, Jacopo Barbieri, Lorenzo Mattarolo, Emanuela Colombo

Politecnico di Milano, Department of Energy, UNESCO Chair in Energy for Sustainable Development, via Lambruschini 4, Milano 20156, Italy

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ABSTRACT

Achieving sustainable energy development in a region requires rational use of energy resources and technologies, and the development of appropriate policies. Three concerns are therefore required to achieve these issues: (i) to acquire a picture of the local current energy situation, (ii) to measure the state of development and the progress towards a sustainable energy system, and (iii) to have energy decision- and policy-makers fully aware of the implications on sustainable development of selected policies. It is in this perspective and in the frame of activities on sustainable energy for all and access to energy in developing countries carried out by the UNESCO Chair in Energy for Sustainable Development, that we developed this review. The objective of this paper is to depict the current energy situation of Africa by using the most up to date data, describing it as far as the concept of sustainable development is concerned, and to see if and how energy policies promoted by local players fit with this asset. We assess the energy situation of Africa by combining (i) data, mainly by the International Energy Agency, about national energy balances for primary and electric energy, the Energy Development Index and energy resources, with (ii) a more comprehensive analysis of the African energy system, accomplished by the Energy Indicators for Sustainable Development. An overview of the energy-related policies and action plans developed by different local players in the African continent is also carried out with the goal of providing remarks by coupling such plans with the above mentioned energy analysis.

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* Corresponding author. Tel.: +39 02 2399 3816.
E-mail address: stefano.mandelli@polimi.it (S. Mandelli).

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1. Africa's energy situation, sustainable development and analysis of current situation and policies

The description of the energy situation of Africa has been only partially addressed in scientific literature. Indeed, peculiarities of the African context are often developed singularly since they are propaedeutic to specific analyses. Examples taken from the wide peer-reviewed literature may be grouped according to some specific topics. A number of papers deal with the situation of *access to energy* and *energy poverty* of the African countries, focusing on the current situation and on measuring and monitoring methods [1–3], and considering driving factors and strategies to support energy access [4–8]. The *link between energy consumption and economic growth* is also often investigated, trying to highlight the key parameters, and hence the most proper policies to promote development [9–14]. Another main topic for Africa refers to current use, potentials and sustainability of *biomass and biofuels* [15–19] as well as analyses of biofuels markets [20,21]. Moreover, within the biomass and biofuels issue, specific considerations are devoted to the pros and cons of *charcoal* [22,23] and *jatropha* [24–26]. Other papers address studies on *energy forecasts and scenarios* for the whole African continent; the aim is to provide quantitative analyses for policy-makers in order to set proper energy strategies. Such studies have a continental perspective [27–29] or a macro-area perspective [30–32]. The Literature is also dedicated to *fossil and renewable energy sources*. In both cases, besides scenario studies [33–39], specific sources are reviewed: hydropower [40], wind [41], solar PV [42,43], LPG and ethanol [44–46], and oil and natural gas [47]. Apart from the literature concerning assessments of specific energy technologies in local contexts, some papers evaluate *renewable-based systems* [48–51] and investigate *new energy system approaches* [52] within a broad African perspective. Lastly, a significant number of papers deal with *power infrastructure. They consider* technical aspects of continental electric grids [53,54], power sector reform [55–59], impact of infrastructure current status on local activities [60] and impact of power sector reform on the energy poor [61].

Even when considering the comprehensive reports developed by international agencies, institutions, NGOs and others, the energy situation of Africa is addressed, on the one hand with singular and specific energy-related topics, and on the other hand within issues related to energy situation for the *developing world* to which most of the African countries belong. For example the International Energy Agency since 2002 dedicated every year a section within the World Energy Outlook to the issue of access to energy in the developing world. The section analyzes specific topics (e.g. energy and poverty, energy for cooking in developing countries, universal access to modern energy, financing universal access) and tracks the progress in the energy development with the Energy Development Index [62,63]. The World Bank shows more interest for analyses of current situation and possible developments of power infrastructure [64–67] and potentials for local exploitation of bio- and fossil-fuels in Africa [68,69]. The energy-related studies developed by United Nations agencies are mostly set within the framework of the Millennium Development Goals. For example, in the case of UNDP, they refer to the developing world [70–72] or specifically to the African context [73].[1]

[1] Further documentation may be found within the publication repositories of many institutions, NGOs and others. Some of them are GIZ, SNV, Practical Action, AFREPREN/FWD, and the African Development Bank.

To our knowledge within peer-reviewed literature, only Karekezi [74] summarized the energy situation of Africa, while a number of analyses for selected countries may be found in the literature [75–82]. Furthermore Lior, in his last paper about the world situation of sustainable energy development [83], dedicated a section to Africa (*A reminder of Africa, a forthcoming global energy development frontier*) and he stated that "*Most global energy reviews focus on the largest energy users or environmental transgressors, usually ignoring commensurate mention and analysis of Africa*".

With our review, we want to specifically depict the energy situation in Africa showing its interconnection with sustainable development. Indeed we employ the Energy Indicators for Sustainable Development (EISD) [84,85] to embrace the conceptual framework of sustainability as introduced through the Agenda 21. The same approach has been already used to analyze the sustainable energy development of several countries and regions and some examples are [86–93]. Furthermore the EISD framework can help policymakers to assess and monitor the impact of energy policies on sustainable development. Therefore, we also describe the current energy-related policies and action plans developed by key local players in Africa and we provide an analysis of such policies and the main features of the energy situation in the light of the EISD framework.

In Section 2 we set the background for the energy situation analysis by introducing the current socio-economic situation of Africa. Section 3 addresses extensive indicators and information that are commonly used when describing energy balances and energy resources of a country such as Total Primary Energy Supply (TPES), Total Final Consumption (TFC) and electricity generation. We also introduce in this section the main characteristics of the power sector and finally we describe the Energy Development Index (EDI) as the indicator of the energy-development nexus. Sections 4 and 5 are dedicated to fossil and renewable resources. Then the African energy situation is further and deeply analyzed in the light of energy sustainable development by computing and reviewing the EISD indicators (Section 4). In Section 5 an overview of the main policies and action plans proposed by African players is carried on. Finally Section 6 summarizes the main issues of the energy situation and identifies the policies and action plans that address such issues highlighting directly and indirectly targeted EISD indicators.

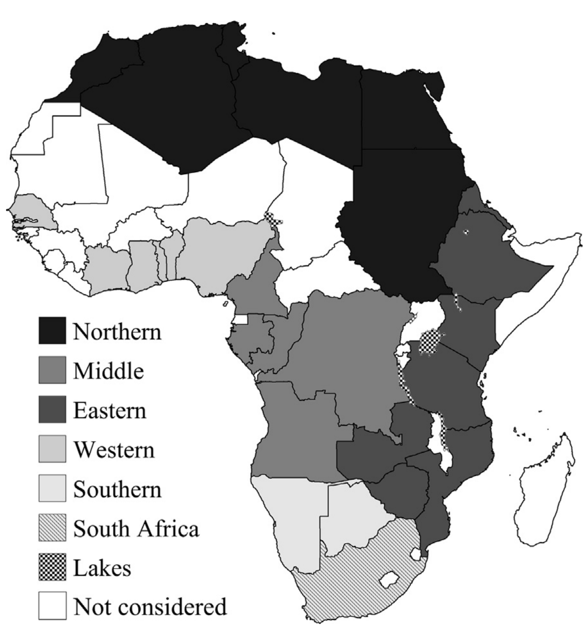

Fig. 1. Countries considered in the review grouped according with UN sub-regions.

Table 1
List of countries considered in the review.

Northern Africa	Middle Africa	Eastern Africa	Western Africa	Southern Africa
Algeria	Angola	Eritrea	Benin	Botswana
Egypt	Cameroon	Ethiopia	Cote d'Ivoire	Namibia
Lybia	Congo	Kenya	Ghana	
Morocco	Congo DR	Mozambique	Nigeria	South Africa
Sudan	Gabon	Tanzania	Senegal	
Tunisia		Zambia	Togo	
		Zimbabwe		

In computing the indicators, we refer to the Energy Balances of non-OECD countries provided by the International Energy Agency (IEA) [94,95] for the energy data, while for the socio-economic data we mainly refer to the World Bank database [96]. When possible we develop indicator time series up to 2010 according to the data available in the 2012 edition of the IEA Balances, and different reference years are otherwise reported. Time series are built with the available and uniform data of years 1980, 1990, 2000, 2008, 2009 and 2010. We consider only the African countries which have co-operative working relationships with IEA and for which IEA provides data. They are 27 countries out of a total of 58 countries as for UN geoscheme of Africa [97]. We refer to them as *Africa IEA*. We carry out the analysis by grouping these countries according to the 5 African sub-regions as defined in the UN geoscheme of Africa. We also separate South Africa from its own sub-region (Southern Africa) and we compute its indicators separately in order to highlight the marked differences between Southern African and Africa IEA as well. Fig. 1 and Table 1 show the countries grouped according to the related sub-regions. When relevant, we compute also indicators for European Union 27 (Europe 27) and we carry out comparisons with Africa IEA and sub-regions.

2. Socio-economic profile

Africa is the world third-largest and the second-most populous continental region. The countries we consider cover about 74% of the total surface area and about 81% of total population of Africa. For comparison, the total surface area and population of Europe 27 are about 20% and 62% of Africa IEA values (Table 2). On the contrary, population density of Africa IEA is much lower than in Europe 27 (36.9 and 116.2 inhabitants per km^2 respectively) due to (i) geography and climate, (ii) historic events and low incomes (i.e. poor living conditions) that limited population growth in the past.

2.1. Population and income growth

Nowadays Africa is characterized by a high rate of population and income growth. The huge population growth began in the second half of the 20th century with almost a quadruplication of the population from about 230 to about 810 million people [100]. Average rate of growth for Africa IEA in 2010 was above 2.1% with Eastern, Middle and Western Africa that increased by about 2.5%. For comparison, Europe 27 had a rate of growth of about 0.3% [96]. One of the main reasons for the fast growth of population is the reduction in child mortality rates, despite sub-Saharan Africa still having the world's highest mortality rate [96], combined with a slow decrease in fertility rates [101]. With the current demographic trends, the African population will be 1.47 billion in 2025 and 2.39 billion in 2050 [100]. This figure could probably have

Table 2
Brief profiles of Africa sub-regions, Africa IEA and Europe 27: selected indicators (2010).

	Area [km^2]	Population [thousand]	GDP_{PPP} pc [2005 USD]	TPES pc [toe]	TFC Electricity pc [kWh]	CO_2 pc [ton]
Northern	8,258,700	199,049	5188	0.88	1134	2.06
Middle	4,676,670	110,195	1774	0.44	158	0.26
Eastern	4,692,320	222,446	1051	0.46	200	0.16
Western	1,853,040	229,864	1947	0.62	156	0.31
Southern	1,406,020	4290	8954	0.90	1518	1.85
South Africa	1,219,090	49,991	9497	2.74	4278	6.94
Africa IEA	**22,105,840**	**815,835**	**2969**	**0.74**	**667**	**1.11**
Europe 27	**4,324,782**	**502,334**	**27,696**	**3.42**	**6293**	**7.43**

Authors' elaboration based on [94,96,98,99].

Table 3
Shares of urban and rural population as % of total population (2010).

	Urban	Rural
Northern	51.2	48.8
Middle	43.0	57.0
Eastern	24.0	76.0
Western	48.5	51.5
Southern	48.7	51.3
South Africa	61.5	38.5
Africa IEA	**42.5**	**57.5**

Authors' elaboration based on [96].

negative impacts on people's quality of life: for example adding more pressure on the agricultural sector, leading to soil impoverishment and increasing risk of famine [102] or exacerbating consequences of unplanned urbanization such as slums dwellers increase [101,103]. Nevertheless, this trend, combined with the increase of average life expectancy, will also lead to a huge expansion of the labor force, and in the next decades Africa could approach China in terms of the available workforce [101].

Furthermore favorable demography, together with high increases of revenues from natural resources and development of manufacturing and service sectors, is a cause of the African economy's fast growth that appeared in the last decade. Over the ten years to 2010, six of the world's ten fastest-growing economies were in Africa and forecasts show that, on average, Africa's economy will outpace Asia over the next five years [104–106]. For a comparison, while in the last decade African annual real GDP growth had been about 5% [107], in Europe 27 it had been slightly above 1% [108]. Despite the economic growth enthusiasm, there are evident disparities among countries and still large segments of the population live under the poverty line. Looking at the total GDP, ten countries (South Africa, Egypt, Nigeria, Algeria, Morocco, Angola, Tunisia, Libya, the former unified Sudan and Ethiopia) contributed to produce about 75% of Africa's GDP, and although the others produce 25% of Africa's GDP, their population is only half that of the continent [109]. Moreover, considering $ 1.25 a day as international poverty line [110], 47% of total population of sub-Saharan Africa fell within the poverty threshold in 2008 [111]. The high ratios of population living in extreme poverty are reflected at macro-economic level in the low values of income per capita: the GDP per capita in the Europe 27 is more than 9 times higher than in Africa IEA, about 3 times higher than in South Africa (the largest African economy) and about 26 higher than in Eastern Africa (Table 2). Clear-cut disparities are also within Africa, and three blocks of countries can be recognized: (i) South Africa has the highest income and its economy drags the neighboring countries too (i.e. Southern Africa countries), (ii) Northern Africa follows with GDP per capita about 50% smaller than South Africa, and (iii) Middle, Eastern and Western Africa are tail-end with GDP per capita about 80% lowerer than South Africa. South Africa and Southern African countries can be considered *diversified established economies*, i.e. they have relatively high levels of income and they do not have high dependence on natural resources and/or agriculture; Northern Africa countries can be considered as *resource-driven economies*, i.e. they rely on extractive fossil fuel resources; several countries in Middle, Eastern and Western Africa can be considered as *emerging economies*, i.e. they have relatively low levels of income, rapid growth rates and high dependence on agriculture. Nevertheless, this characterization does not apply exactly to all the countries within a sub-region [107].

2.2. Urban–rural divide

A further feature of Africa, as well as of the *developing world*, is the clear disparity between urban and rural areas. The majority of the Africa IEA population lives in rural areas (Table 3) and the distribution within the sub-regions between urban and rural varies according with the specific economy structure. While it is not correct to claim rapid urbanization of Africa, and instead the urban growth rates in most Africa countries generally follow the national population trends [112], it is undoubtedly true that underdevelopment and poverty are predominantly rural phenomena [103,113]: indeed about 70% of the poor people live in rural areas [114]. Generally these areas are populated in a scatter manner, geographically isolated and difficult to access [115]. They are also characterized by high illiteracy rate, lack of access to health care, infrastructure and clean water supply [116]. Considering as representative of rural-urban disparity the comparison carried out by Sahn and Stifel [103] with 8 living standards indicators[2] for 24 sub-Saharan African countries, it emerges that *“standards of living in rural areas almost universally lag far behind urban areas”*. On the other hand, large disparities appear when comparing African urban areas with those in developed countries [117]: to improve basic infrastructure and communication networks, to address public transport and environmental conditions and to respond to high inequalities (i.e. reducing proportion of slum dwellers) are among the main issues African cities have to tackle [118].

2.3. Human Development Index

The state of the current socio-economic conditions of Africa that we have depicted so far can be further completed by considering the Human Development Index (HDI) introduced by UNDP in 1990 [119]. HDI aggregates different information since it considers the following indexes: Life Expectancy Index (LEI), Education Index (EI), and Income Index (II). In more detail, it results from the aggregation of the following indicators: (i) life expectancy at birth, (ii) mean years of schooling and (iii) expected years of schooling, and (iv) Gross National Income (GNI) per capita. The method for HDI calculation has been gradually improved until the current formulation was introduced in 2010 [120]. The index can be seen as a measure of human capability referring to the opportunities that a person can have all along his/her life [121]. As a matter of facts, it is “*an index that captures the three essential*

[2] Asset poverty, enrollments, ratio of girls-to-boys enrolled, infant mortality rate, neonatal care with skilled personnel, contraceptive use, child stunting and adult malnutrition.

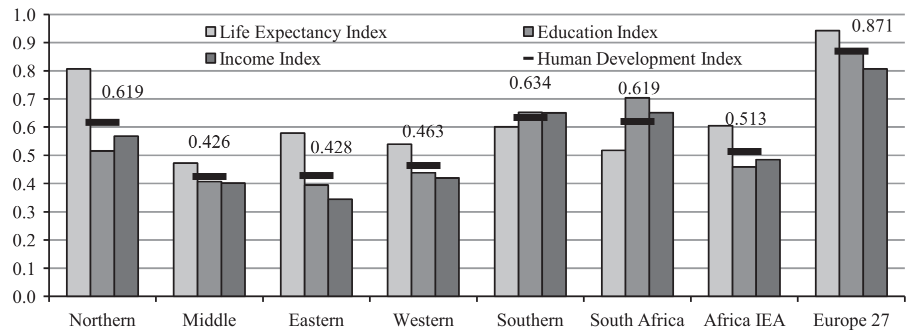

Fig. 2. HDI and HDI components. Authors' elaboration based on [96,122].

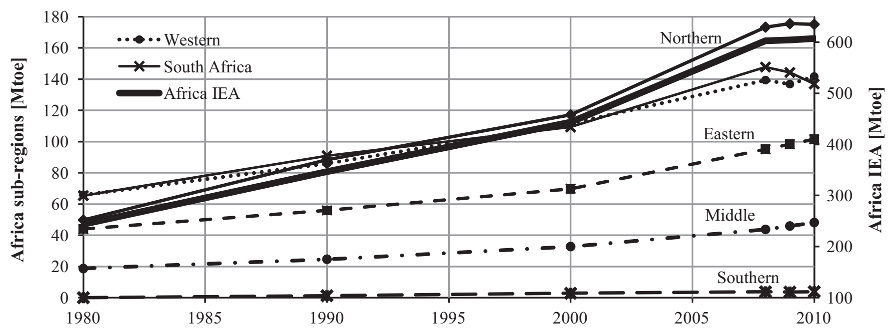

Fig. 3. TPES trend for African sub-regions (left axis) and Africa IEA (right axis). Authors' elaboration based on [94,95].

components of human life […] longevity and knowledge refer to the formation of human capabilities, and income is a proxy measure for the choices people have in putting their capabilities to use" [119].

Fig. 2 shows both the values of each dimension of the HDI and the overall value for Africa IEA, African sub-regions and Europe 27. Different conditions are evident among the different African sub-regions, and between Africa IEA and Europe 27. Northern and Southern Africa are the sub-regions with the higher HDI values, with a score around 0.62. LEI has a particularly high value in Northern Africa, while Southern Africa has similar values for all the three indexes. South Africa has the same HDI as Northern Africa, but the index results from a rather different composition of the three dimensions. In particular LEI is much lower, while EI and II are higher. Eastern, Middle and Western countries have very low values of each indicator: they are tail-end not only in Africa, but also in the world. Eventually, a comparison between Africa IEA and Europe 27 clearly underlines a huge gap with a value of HDI around 0.51 for Africa IEA and around 0.87 for Europe 27.

3. Current scenario of African energy situation

Hereafter we set the frame of the energy situation of the Africa IEA and the African sub-regions by means of (i) three indexes defined within the ordinary country energy balances [94] (Total Primary Energy Supply, Total Final Consumption and Electricity generation), (ii) a description of the main characteristics of power sectors (i.e. installed capacity and security of the supply) and (iii) the analysis of the Energy Development Index [123]. The energy situation assessment is then completed by the analysis carried out with the selected Energy Indicators for Sustainable Development and described in the next paragraphs.

3.1. Total Primary Energy Supply (TPES)

The TPES of Africa IEA and sub-regions is constantly increasing due to the population and economy growth of the whole continent (Fig. 3). Northern, Western Africa and South Africa contributed almost in equal measure to about 66% of the total 2010 TPES and their strong influence is reflected on the 2009–2010 TPES contraction for Africa IEA that is deeply linked to the economic crisis. South Africa has been the country most subjected to the crisis due to the economy connections with Europe and US [107]. TPES values reflect differences in population and economy development of the African sub-regions (Table 2): (i) Northern Africa has a total population similar to Eastern and Western Africa, but the economy is much more developed (i.e. higher GDP per capita and energy supply per capita), thus the TPES is higher; (ii) in 2010 South Africa counted for about 20% of TPES of Africa IEA despite the fact that its population is about 6% of Africa IEA, indeed South Africa is the largest and most developed economy in Africa and hence it has the highest TPES per capita; (iii) Eastern and Middle Africa have similar *emerging economies* and the TPES values reflect the difference in total population.

3.2. Total Final Consumption (TFC)

The trend of TFC of Africa IEA mirrors the TPES increase (Fig. 4) and the difference between them is given by two main equally contributing dimensions: (i) the efficiency of oil refineries, electricity and CHP plants, and (ii) industry own use and losses. The effect of the economic crisis is evident also for the TFC, but it reflects only the contraction of the South Africa economy and the consequent reduction in consumption of oil and coal & peat which together cover more than 50% of the South Africa TFC (Fig. 5). Consumption of natural gas has remained almost constant from 2008 to 2010 due to a significant decrease in the rate of growth in Northern Africa which accounted for 92% of 2010 Africa IEA natural gas share. The electricity consumption, despite a slight contraction in the rate of growth, has continued to increase. In this case the crisis has had a minor effect since the results of policies and interventions towards increasing access to electricity (mainly in Middle, Eastern and Western Africa) have balanced the

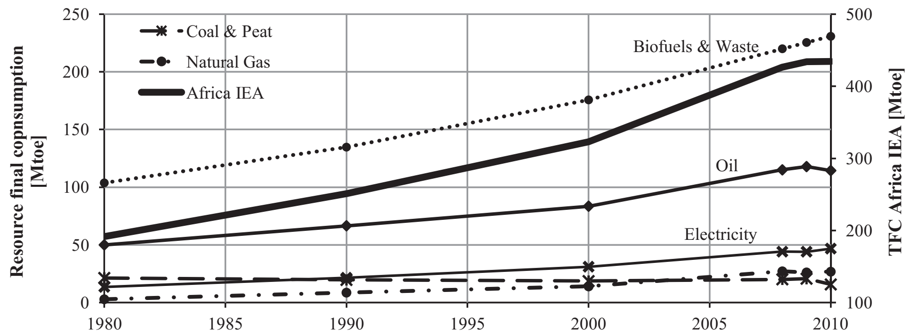

Fig. 4. Trends of final consumption of energy resources (left axis) and TFC for Africa IEA (right axis). Authors' elaboration based on [94,95].

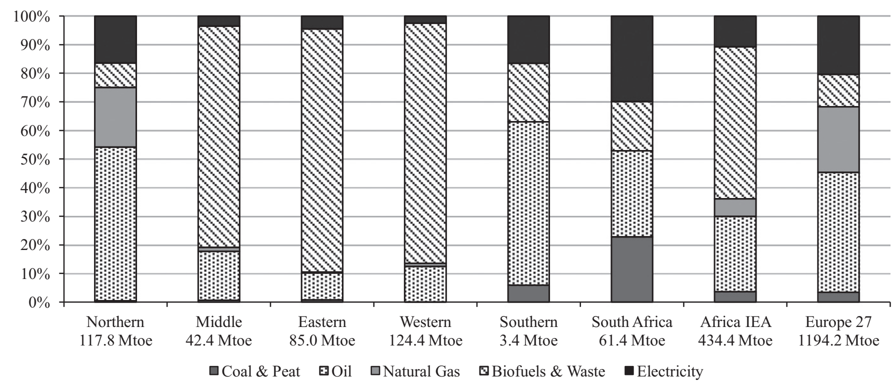

Fig. 5. TFC total values (beneath region labels) and shares by resources (2010). Authors' elaboration based on [94,95].

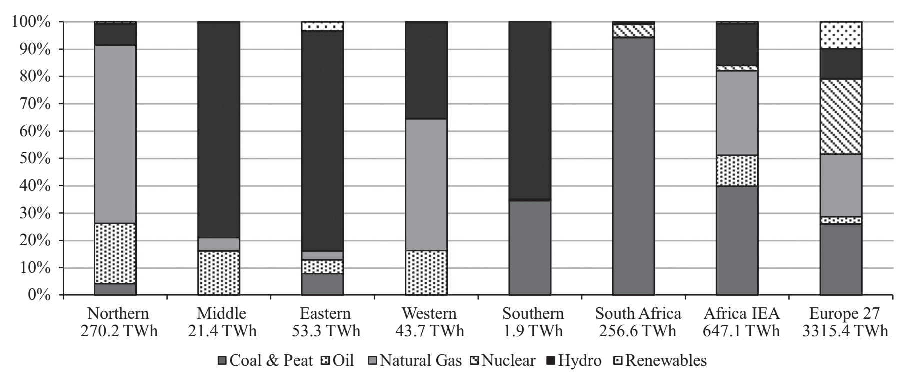

Fig. 6. Electricity generation total values (beneath region labels) and share by resources (2010). Authors' elaboration based on [94,95].

consumption decrease in the productive sectors of the most developed countries (South Africa and neighbors).

A key feature of energy in Africa is the pivotal role that biofuel & waste play in the supply and consumption. In 2010 biofuel & waste counted for about 53% of TFC of Africa IEA (Fig. 5) and the crisis has not affected the rate of growth (Fig. 4). In the frame of Africa, and specifically in sub-Saharan Africa, biofuel & waste is associated to all the different typologies of traditional fuels (firewood, agricultural residues, dung, charcoal) that local poor population exploits for its livelihood. Biofuel & waste is the primary source consumed in the poorest economies of the continent, i.e. in Middle, Eastern and Western Africa, with 77%, 85% and 84% of the TFC respectively. These three sub-Saharan sub-regions have a similar share-out of resources in TFC that, besides biofuel & waste, is made up of oil (mainly for the transport sector) and electricity, with shares ranging between 10–17% and 4.5–2.5% respectively (Fig. 5). The economies of Northern, Southern Africa and South Africa are more developed when compared to the three sub-Saharan sub-regions: electricity consumption becomes relevant due to higher electrification rates (i.e. higher consumption within residential and service sectors) and significant contribution from the industrial sector; oil shares also increase driven by larger transport sectors, and hence the shares of biofuel & waste decrease down to a share of 8.5–20%. Moreover significant consumptions of natural gas (about 21%) and coal (about 23%) are the peculiarities of Northern Africa and South Africa respectively (Fig. 5). At continental level, TFC of Africa IEA was about 36% of Europe 27 (2010) and the energy mix is very different.

3.3. *Electricity generation*

In 2010 electricity generated in Africa IEA was 647.1 TWh (about 19.5% of the Europe 27 value), of which 81% was equally generated in Northern Africa and South Africa (Fig. 6). Northern Africa has a lower consumption per capita than South Africa (almost 4 times lower), but it reaches the highest generation value

among African sub-regions due to higher population. Middle and Western Africa have similar electricity consumption per capita and the difference in the total electricity generated arises from the different amount of population, while the slightly higher consumption in Eastern Africa leads to greater electricity generation than Western Africa, despite the lower population (Fig. 6 and Table 2).

Considering the energy mix, it can be noticed that each sub-region mainly relies on its own indigenous energy resources (Fig. 6) since inter-state trades of fossil fuels are minimal [124]. Middle, Eastern and Western Africa, that include many *emerging economies*, heavily rely on hydropower that is the cheapest, well-known, indigenous energy source; in this aspect they are following the same path as Europe for its electrification [125]. Nevertheless, Western Africa has also a significant share of electricity generated with natural gas that is mainly related to the exploitation activities in Nigeria. Hydropower share in the other sub-regions is low: Northern Africa relies mostly on oil and natural gas, 65.4% and 22.0% respectively, while South Africa relies on coal that counts for 94.2% of total generation. Lastly, it has to be mentioned that South Africa is the only country in Africa that has a nuclear power plant (the Koeberg plant) that has two PWR reactors for 1.8 GW installed capacity. Comparing Europe 27 with Africa IEA (Fig. 6), the differences are made by a lower use of oil (2.6% in Europe 27 and 11.3% in Africa IEA), and a higher exploitation of nuclear power (27.6% and 1.9% respectively) and renewables other than hydropower (10.0% and 0.7% respectively).

3.4. Power sector

The literature that addresses the African power sector is quite developed. Therefore, we report in [53–61,64–67,126–131] selected literature related to power sector analysis, while in the following we introduce the African power pools focusing on power installed capacity and reliability of the supply.

Within Africa there are five power pools that refer to the respective African Regional Economic Communities and that promote regional projects and trades among them. The pools are (i) the *Comité Maghrébin de l'Electricité (COMELEC)*, (ii) the *Central African Power Pool (CAPP)*, (iii) the *Eastern Africa Power Pool (EAPP)*, (iv) the *West Africa Power Pool (WAPP)*, and (v) the *Southern Africa Power Pool (SAPP)*. Regarding the installed power (Table 4), SAPP has the highest capacity (about 40% of total African value), followed by EAPP and COMELEC (about 22%), WAPP (about 11%) and CAPP (about 5%). Some countries play a pivotal role within their own pool: Algeria holds 41% of installed capacity in COMELEC, Egypt 78% in EAPP, Nigeria 60% in WAPP, and South Africa 82% in SAPP. Most of the existing capacity of Africa comes from thermal plants, but the share of hydropower is expected to grow in the future due to ongoing large projects in EAPP, WAPP and SAPP [128]. COMELEC and SAPP have the highest capacity per thousand habitants and this value drops significantly for the other pools. On the other hand, for comparison, Europe 27 in 2009 had a total installed power of about 840 GW with about 1670 kW per thousand habitants [132]. For Africa, the lower installed capacity per capita is an indicator of the poor access to electricity mostly among households which, in addition, in sub-Saharan Africa face tariffs about twice higher than other parts of the developing world [67].

A major problem of the power infrastructure, especially for sub-Saharan pools, is the low level of reliability of the supply that is exacerbated by the lack of links between the regional networks [67]. According to the World Bank enterprise surveys [133], which provide a useful measure of the reliability of grid-supplied power, most African enterprises experience frequent outages which lead to significant loss of productivity [60]. Among the five world regions listed in the World Bank survey, South Asia has the highest amount of average power outage days per month between 2000 and 2008, followed by sub-Saharan Africa (Table 5). Sub-Saharan African firms often identify electricity as a main constraint in doing business [60,133], and own generation facilities (i.e. diesel gensets) are very popular among them. Indeed own gensets constitute a significant proportion of the total installed power capacity of the sub-Saharan sub-regions: while in East and Middle Africa own generation is about 8%, in West Africa it reaches 19% [129]. A further phenomenon caused by chronic power shortages is the increasing use of grid-connected emergency power. In this case, countries enter into short-term leases with specialized operators that install new capacity much faster than traditional power generation projects [67]. Like own gensets, emergency power in some cases constitutes a significant proportion of total installed capacity (even tens of percentage points) and related costs can reach a few percentage points of GDP [130].

Table 4
Total power installed capacity and key indicators for African power pools.
Source [128].

	COMELEC 2009	CAPP 2009	EAPP 2008	WAPP 2010	SAPP 2010
Installed capacity (GW)	27.35	6.07	28.37	14.09	49.88
Hydropower share	8%	86%	24%	30%	17%
Thermal share	91%	14%	73%	70%	83%
kW/1000 habitants	319	49	74	54	311

3.5. Energy Development Index

The Energy Development Index (EDI) has been devised by IEA in order to underline and specify the role that energy plays in human development [62]. In this sense it can be considered as an index that gives a summary of the main critical aspects regarding the energy issue in developing countries. In particular, the index tracks the progress of a country or a region towards the use of modern fuels (electricity, LPG, natural gas, kerosene, paraffin, ethanol and biofuels [123]) and modern energy services. In order to better reach the objective, the index has been recently redefined [123]: in the latest version EDI is the combination of two main indicators, i.e. the household indicator and the community indicator. Each of them is in turn a combination of two other indicators referring to (i) access to electricity and (ii) access to clean cooking facilities for the household indicator; (iii) access to energy for public service and (iv) access to energy for productive use for the community indicator.

Fig. 7 shows EDI and its components for each African sub-region and for Africa IEA. The difference in the scores among Northern and Southern Africa, and the other sub-regions is evident. Northern and South Africa have similar EDI values, but

Table 5
Electric outages and related sale losses (average values 2000–2008).
Source [133].

	Number of outages (days per month)	Duration of the outages (hours)	Loss due to electrical outages (% of annual sales)
Sub-Saharan Africa	10.30	6.70	5.84
Middle East and Northern Africa	2.87	3.45	4.21
East Asia and Pacific	5.19	3.14	2.76
Latin America	2.68	7.59	4.19
South Asia	42.21	4.56	10.81
World	8.48	5.56	4.86

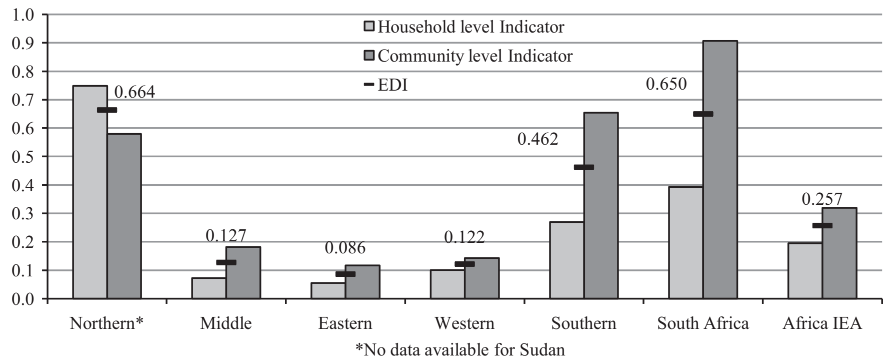

Fig. 7. EDI and EDI components (2010). Authors' elaboration based on [95,98,123,134].

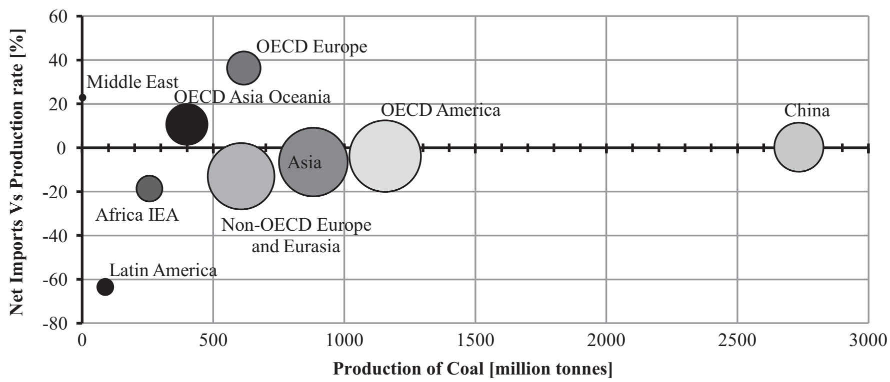

Fig. 8. Net import, production and proven recoverable reserves of coal. Authors' elaboration based on [134,135].

they show different contribution of the two components: while for Northern Africa the household and community indicators are not much different, South Africa components are clearly unbalanced towards the last one. Specifically, modern fuels almost supply all the residential TFC in Northern Africa while large segments of South Africa population rely on traditional fuels, hence the household indicator is higher for Northern Africa than South Africa, which suffer the energy access disparities within its population. On the contrary South Africa has higher consumption of electricity than Northern Africa in the public services; hence the South Africa community indicator is higher. Moreover Northern Africa is the only sub-region where the household indicator overcomes the community one. This is a consequence of low consumption of electricity in the public services (i.e. low development of this sector) compared to the access to modern fuels in the residential sector. Considering the other sub-regions, Southern Africa follows Northern and South Africa and the difference between the two EDI components mirrors the situation of South Africa, while Middle, Eastern and Western Africa are tail end both for EDI and EDI components at the African and at the world level too. For these sub-Saharan sub-regions, the poor household indicators are consequence of the acute lack in access to modern fuels in the domestic sector which basically relies only on traditional biomass, while the poor community indicator is affected by very low consumption of electricity within the public service and meager TFC for productive uses due to the underdevelopment of the public service and productive sectors. Lastly, it is worth noting that among the African countries, the first position in the EDI ranking is occupied by Libya, followed by Egypt and then Algeria. On the other hand, Ethiopia occupies the last place in both the African and the global ranking [123]. The critical conditions due to corruption, population living in rural areas, population density, and low government effectiveness, are the main factors that explain the poor level of energy development, especially in Sub-Saharan Africa [4].

4. Fossil resources assessment

In the next paragraphs coal, oil and natural gas reserves and production are analyzed by comparing macro-regions at the global level in order to make evident differences among the African continent and other areas. This analysis is particularly significant since most of the fossil fuels extracted in Africa are exported. Moreover, some information about African sub-regions and single countries are given. South Africa has been included in the Southern Africa sub-region since no disaggregated data are available.

At the end of 2008, the continent had over 130 billion barrels of oil proven recoverable reserves (i.e. crude oil and natural gas liquids), 14 trillion cubic meters of natural gas proven recoverable reserves,[3] and 31 billion tonnes of coal proven recoverable reserves [135]. Nevertheless, most of fossil resources are exported to meet the needs of other areas of the world, mainly the United States, China and Europe [136]. Moreover, resources in Africa are unevenly distributed, and the interstate energy trade is minimal. This fact leads to significant differences in the use of fossil resources in the various regions of Africa [124].

In Fig. 8 the *x-axis* measures total production of coal, while the *y-axis* compares net imports and production rate: positive values denote net importers, while negative values denote net exporters. Areas of the circles are proportional to the amount of proven recoverable reserves. When compared to other regions of the world, coal reserves (bituminous including anthracite, sub-bituminous and lignite) in Africa are not particularly vast. Similarly, as a producer, Africa occupies the third last place in the

[3] Even if no detailed data are still available in the international databases, it is worthwhile to report that in the years between 2009 and 2013 new important natural gas and oil fields have been discovered in Africa. This issue mostly concerns Eastern Africa, and in particular Mozambique and Tanzania (natural gas), and Kenya, Uganda and Madagascar (oil) [34,267].

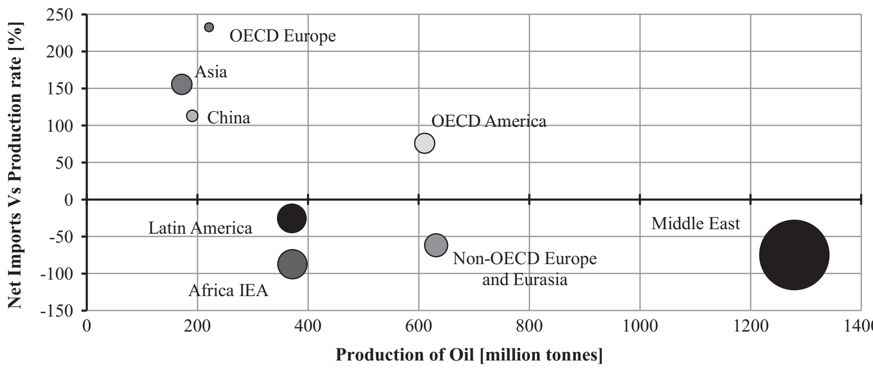

Fig. 9. Net import, production and proven recoverable reserves of oil. Authors' elaboration based on [134,135].

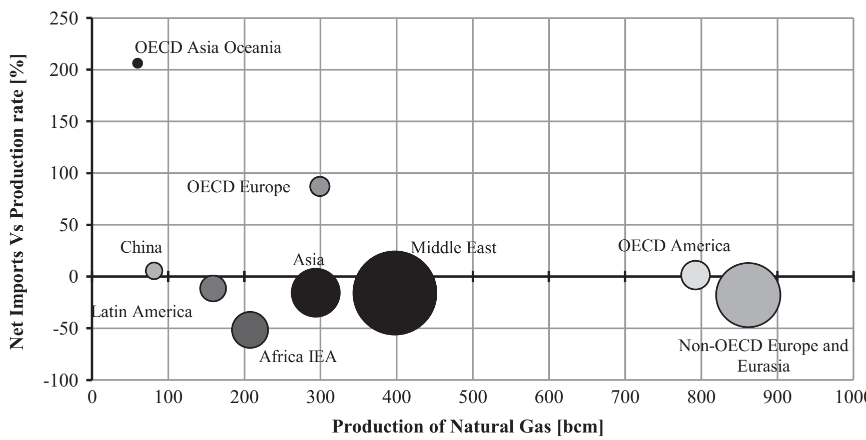

Fig. 10. Net import, production and proven recoverable reserves of natural gas. Authors' elaboration based on [134,135].

global ranking. Nevertheless, in absolute terms, the production is still significant: in 2008 the African continent produced more than 252 million tonnes of coal, and exported about 48 million tonnes, i.e. 18.6% of its own total production. More than 98% of the African coal production occurs in South Africa, where more than 95% of the total reserves of the continent are located. Other reserves are mostly present in Eastern Africa, and particularly in Mozambique, Tanzania and Zimbabwe.

Fig. 9 compares production and import of crude oil and oil products. Africa in 2008 produced nearly 400 million tonnes of oil, and exported about 340 million tonnes, of which about 325 million tonnes from Africa IEA. This makes Africa the first net exporter after Middle East that exported about 959 million tonnes of oil in the same year. African oil proven recoverable reserves are similar to those of Latin America, i.e. about a fifth of Middle East reserves and 11 times the OECD Europe's reserves. Eastern and Southern Africa are the only net importers of oil with 8.6 and 26.8 million tonnes in the reference year, respectively. In particular, South Africa is responsible for almost all the Southern African imported oil. Major producers and exporters among African sub-regions are Northern and Western Africa [35], while reserves and production are near zero in Eastern and Southern Africa. Top-four exporting countries are Nigeria, Angola, Libya and Algeria.

Lastly, Fig. 10 allows the same analysis regarding natural gas. In 2008 Africa produced more than 200 billion cubic meters (bcm) of natural gas, i.e. about two thirds of the OECD Europe production. Nevertheless, African proven recoverable reserves are more than three times OECD Europe reserves, two times Latin America reserves, and one third more than OECD America reserves. The export of more than 50% of the produced natural gas makes the continent the second net exporter among all considered areas, being non-OECD Europe and Eurasia the first ones. In particular, natural gas for exportation is almost totally produced by Northern and Western Africa. Morocco, Tunisia and South Africa are the only African countries consuming imported natural gas. Top-four exporting countries are Algeria, Nigeria, Egypt, and Libya. It is worth noting that reported data refer to marketable natural gas production. In this sense, it is important to mention the gas flaring practice. Globally, the volume of flared gas is declining over the years thanks to increasingly stringent measures pushed by the international community, and in particular by the Global Gas Flaring Reduction Partnership [137]. However, gas flaring still plays a significant role in the African scenario. The worst situation occurs in Nigeria: in 2008 marketable natural gas production in this country was 31.35 bcm, compared with a flared volume of gas of about 15.5 bcm. Another example is Algeria, with a marketable production of 89.27 bcm in the same year, compared with a flared gas volume of more than 6 bcm. At the continent level, more than 36 bcm were flared, i.e. almost 20% of the marketable production [138].

5. Assessment, potential and driving forces for renewable energy penetration

Renewable resources are only minimally exploited in Africa. Indeed renewable power generation capacity is about 28 GW, compared with a total power generation capacity more than 145 GW [131], with hydropower accounting for more than 90% of total renewable energy capacity.

Fig. 11 shows the predominance of hydropower in all the African sub-regions and South Africa. Globally, there are nearly

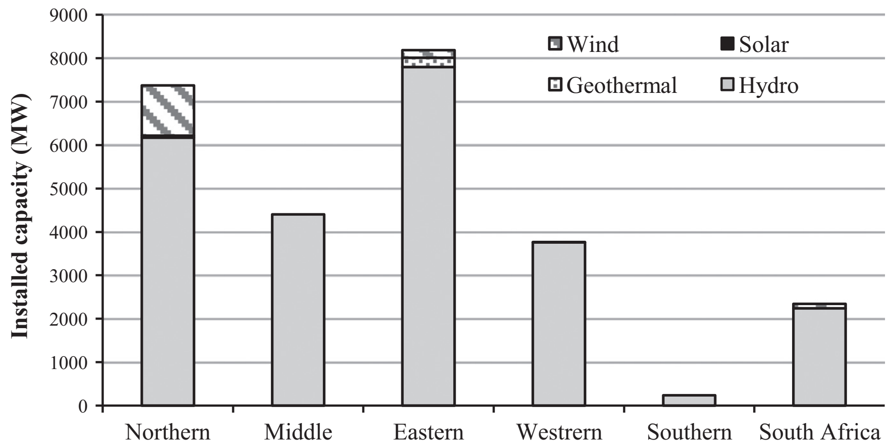

Fig. 11. Installed power capacities from renewable sources (2012). Authors' elaboration based on [139–141].

1,000 operational hydropower plants in Africa, about 400 of which have a capacity of 10 MW or more [131]. Among these plants, 5 have a capacity larger than 1 GW: Aswan (Egypt, 2100 MW), Cahora Bassa (Mozambique, 2075 MW), Inga II (Congo DR, 1424 MW), Merowe (Sudan, 1250 MW), and Akosombo (Ghana, 1020 MW). Wind power plays a significant role only in Northern Africa (mainly in Egypt and Morocco, both having an installed capacity around 500 MW) [41], while geothermal plants are located in Eastern Africa (mainly in Kenya and Ethiopia, with an overall capacity of 217 MW, although exploitation for geothermal resources is ongoing in other countries) [39,142]. There are few large-scale solar plants in Algeria and Morocco, while small-scale PV systems give locally some contribution, particularly in South Africa and Kenya (11 and 3.6 MWp installed respectively) [124]: in fact, these kinds of systems are currently limited to light needs and operation of small loads, such as water pumps, while only few countries employ small PV systems for distributed generation [38]. Lastly, power generation from biomass has not been reported in the graph since its contribution in the selected countries is negligible: most of total installed capacity, which is about 800 MW, is located in Mauritius [61].

As per electricity production from renewable sources, 90% or more of total production is obtained by hydropower in all the sub-regions: as a matter of fact, other renewables contribute to electricity production less than 5% in the average of Africa IEA (Fig. 6). South Africa is an exception, having a contribution of around 15% from other renewables .

On the other hand, biomass plays an essential role as a source of energy for heating and cooking: in 2010 biomass solid fuels (wood and charcoal) provided energy for more than 207 Mtoe to the residential sector, to be compared with a total residential fuel consumption of about 238 Mtoe. Middle, Eastern and Western Africa are the main biomass consumers (28, 67, and 93 Mtoe respectively) [123]. In addition to wood and charcoal, wood wastes from lumber and furniture-making industries are other important biomass sources that can be used. For example, sawdust particles have been used to make briquettes in many rural communities for cooking, water heating, and other uses [38]. However, it is worth noting that biomass should be considered a renewable resource only when forests and other wood sources are managed in a fully sustainable manner [15,16]. In general, this necessary condition is not always satisfied in the African context, as we report in detail when addressing the issue of deforestation (paragraph 6.5). A different case is the use of waste biomass for biogas production: according to Parawira, "*biogas production from agricultural residues, industrial, and municipal waste(water) does not compete for land, water and fertilizers with food crops […]. It also reduces the use of forests resources for household energy purposes and thus slows down deforestation and its subsequent problems*" [143]. However, despite a number of biogas systems have been built, mainly in sub-Saharan countries (Kenya, Burundi and Tanzania are at the top of the list for the number of both small and large installed plants), they actually contribute only minimally to the energy needs of the continent. Inadequate funding or capital availability, a lack of government support, and insufficient knowledge about this technology are just some of the factors limiting the adoption of biogas systems [39]. Moreover, the low contribution to energy needs is also due to the fact that among small scale plants, very few are operational [144].

Table 6
Electricity generation potential from renewable resources in Africa (TWh/year).

	Wind	Solar[a]	Hydro	Biomass	Geothermal
Northern	1014	2025	78	257	–
Middle	120	915	1057	1572	–
Eastern	1443	3953	578	642	88
Western	394	1265	105	64	–
Southern	852	3128	26	96	–
Africa IEA	**3823**	**11,286**	**1844**	**2631**	**88**

Authors' elaboration based on [145].

[a] Solar energy potential considers both photovoltaic and concentrating solar power systems.

Although at present the contribution of renewables to the energy needs of Africa is minimal (except for hydroelectric energy), the renewable energy potential of the continent is enormous: a total electricity generation potential of more than 13,700 TWh/year has been recently estimated by IRENA on the basis of a number of studies [145,146]. The estimation was made excluding some zones, such as water bodies, protected areas, forests, remote lands, and zones which do not meet technical requirements according to criteria defined in [131]. Moreover, only 10% of the remaining lands were taken into account.

Table 6 shows more in detail the estimated potential for each renewable source by African sub-region. All African sub-regions are characterized by abundant resources: wind is particularly abundant in Northern and Eastern Africa, hydro and biomass in Middle Africa, solar energy is available in all areas, and particularly in Northern, Eastern and Southern Africa. Geothermal energy, instead, is relevant only in Eastern Africa, mainly in the Great Rift Valley area. It is interesting to note that in each area there is at

least one renewable resource which is quite abundant even if the others are not. To give an example, the potential of hydro and biomass in Southern Africa is not very high, but the solar potential is huge.

We may argue that wind, solar, hydro and biomass each could supply the entire African electricity demand. In particular, Table 7 shows how solar energy alone could provide more than 2000% of the electricity TFC of Africa IEA. From the same table it is evident that both wind and solar energy potential are much higher than TFC everywhere.

African countries are endowed with energy resources, both fossils and renewables, but often they are unable to exploit them to improve their energy systems. Indeed, despite the progress made in the last decades, barriers still exist to promote sustainable energy solutions. Reasons are different and have endogenous and exogenous origins mainly referring to institutional, economic and cultural dimensions [147]. One of the main barriers is the mobilization of the private sector actors for providing the required economic means and key expertise for the scaling-up of sustainable energy solutions. In this scenario, a key role for renewable energies is defined. Although renewable energies may not be the only answer when high reliability and high energy density are required (i.e. industrial processes, transportation), they have a number of direct advantages [148]:

- they are deployable in a decentralized and modular manner;
- in some areas they are closed to “grid parity” due to increased cost for other sources;
- exploiting the high potential of domestic resources they may increase energy security, while reducing national imports and related costs;
- they can support efficiency increase without decreasing economic output or lowering standards of living;
- they may open new export or revenue opportunities by being eligible for carbon crediting on carbon markets;
- they could encourage coherence and greater networking among their member states to promote sharing of experiences and best practices thus contributing to increase regional integration.

In addition the dissemination of renewable-based off-grid systems it represents an effective way to promote sustainable development in many rural areas. Indeed

- they are promoted within the frame of green economy, but vice versa; a more inclusive and equitable, participatory and innovative approach can speed up the penetration of renewable energies [149–152],
- the new concept of innovative democracy coupled with stable financial support schemes may be one of the drivers allowing different players to engage in renewable energies both in developing and developed countries [153,154].
- community-based organizations and self-help groups can play an important role in empowering the community and making it responsible for managing public goods [155,156].

Table 7
Electricity generation potential from renewable resources as share of electricity TFC (%).

	Wind	Solar[a]	Hydro	Biomass	Geothermal
Northern	449	898	35	114	–
Middle	688	5245	6059	9011	–
Eastern	3240	8875	1298	1441	198
Western	1096	3520	292	178	–
Southern[a]	416	1527	13	47	–
Africa IEA	**724**	**2136**	**349**	**498**	**17**

Authors' elaboration based on [94,95,145].

[a] Solar energy potential considers both photovoltaic and concentrating solar power systems.

Moreover, energy access provided mainly by renewable energies may have a direct impact on human development and capacity building since they are instrumental for developing other sectors. As stated by Sovacool [157], renewable-based technologies act as boosts for the education sector: training is needed to have the required work force at different education levels. Moreover, technical competences but also facilitator and communication skills are essential, and research and innovation capacities need to be developed within the local academia. Furthermore, when capacity building is properly set up within local communities and industries other benefits may be added: employment opportunities may increase, policies and strategies can be better assessed, local acceptance is easier to be established and local technical reliance is more prompt, thus increasing the multiplier effect of renewable energies.

6. African energy system analysis via Energy Indicators for Sustainable Development

The complete set of Energy Indicators for Sustainable Development (EISD) consists in 30 indicators [84]. Four indicators refer to the social dimension, sixteen to the economic dimension, and ten to the environmental dimension. In the framework of this work, we selected only some indicators for two reasons: (i) relevance in relation to the African specific context and (ii) data availability. To give an example, ENV9 (Ratio of solid radioactive waste to units of energy produced) was excluded from the analysis, since no country except South Africa has a nuclear reactor, and no data about radioactive waste from other energy fuel cycles are available. In the end, we considered 17 indicators in the analysis. In some cases, we modified the original definition in order to make their evaluation possible using available data. Selected and computed indicators are listed and described in Table 8. Any change with respect to the original definition is underlined in the description.

In order to make the presentation and the discussion clearer and to provide a framework for the analysis between the energy situation and policies, we grouped the selected indicators as shown in Table 9. We define the first set of indicators as *Energy sector indicators* since they contribute to depict the conditions of the energy sector alone (i.e. no economic or social quantities, like GDP, values added, population, are considered by the indicators in this group). The definitions of the other sets of indicators refer to the indicators subject matters.

6.1. Energy sector indicators

6.1.1. ECO3 Share of losses in total electricity generation, transmission and distribution

ECO3 refers to electric system losses in generation, transmission and distribution: Table 10 shows ECO3 as losses as a share of total electricity generation. We computed electricity losses of each sub-region by using values of *Total Electricity Generation*, *Net Imports of Electricity* and *Final Electricity Consumption* available in [94,95]. Taking as reference the Europe 27 value, that reflects the minimal technical losses, the Africa IEA value is more than twice greater. South Africa, that has the most advanced electric systems, reaches 8% while all the other sub-regions have values above 10%. These figures bring out both the poor conditions of transmission

Table 8
Selected EISD indicators.

Acronym	Indicator	Description
ECO2	Energy use per unit of GDP	Ratio of TPES and Electricity use to GDP
ECO3	Efficiency of energy conversion and distribution	Share of losses in total electricity generation, transmission and distribution
ECO4	Reserves-to-production ratio	Ratio of proven recoverable reserves remaining at the end of a year to the production in that year
ECO6	Industrial energy intensities	TFC per unit of value added in the industrial sector
ECO7	Agricultural energy intensities	ECO7 (TFC per unit of value added in agriculture) and ECO8 (TFC per unit of value added in the service and commercial sector) are merged into the indicator *Energy intensities other than industrial, transport and household* (TFC per unit of value added in the agriculture and service sector) [a]
ECO8	Service/commercial energy intensities	
ECO9	Household energy intensities	TFC per capita in the residential sector
ECO10	Transport energy intensities	A proxy for ECO10 is computed as the TFC of transport sector per capita instead of per unit of km travelled [a]
ECO11	Fuel shares in energy and electricity	Shares of energy fuels in TPES, TFC and electricity generation
ECO15	Net energy import dependency	Ratio of net import to TPES or production in a given year in total and by energy source
ENV1	Greenhouse gas (GHG) emissions from energy production and use per capita and per unit of GDP	Emissions of GHGs from fuel combustion per capita and per unit of GDP. Only carbon dioxide is considered [a]
ENV2	Ambient concentrations of air pollutants in urban areas	Complete set of data is not available. Analysis based on literature information is carried out. Moreover we introduce further considerations to highlight the issue of Indoor Air Pollution (IAP) [a]
ENV6	Rate of deforestation attributed to energy use	No quantitative data available, but a qualitative analysis is carried out
SOC1	Share of households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy	Share of rural and urban population with no access to electricity, or heavily dependent on traditional fuels and coal (i.e. solid fuels)[a]
SOC2	Share of household income spent on fuel and electricity	No quantitative data available, but a qualitative analysis is carried out
SOC3	Household energy use for each income group and corresponding fuel mix	No quantitative data available, but a qualitative analysis is carried out
SOC4	Accident fatalities per energy produced by fuel chain	A proxy for SOC4 at the household level is computed as DALYs per 1000 people due to IAP for solid fuels combustion [a]

[a] The definition of this indicator has been modified by the authors.

Table 9
Selected EISD indicator grouping.

	Group	Selected EISD
1	Energy sector indicators	ECO3, ECO4, ECO11, ECO15
2	Household energy indicators	SOC1, SOC3
3	Energy intensity indicators	ECO2, ECO6, ECO7, ECO8, ECO9, ECO10
4	Emission and pollution indicators	ENV1, ENV2
5	Deforestation indicator	ENV6
6	Household energy affordability indicator	SOC2
7	Household energy-health indicator	SOC4

Table 10
ECO3 (2010).

	ECO3 (%)
Northern	12
Middle	13
Eastern	14
Western	16
Southern	32
South Africa	8
Africa IEA	11
Europe 27	5

Authors' elaboration based on [94,95].

and distribution grids of Africa IEA, and also the widespread phenomenon of non-technical losses (i.e. illegal connections, unmetered energy, metering inaccuracies, etc.) that greatly affects ECO3 within the context of Africa (and generally of Developing Countries) [158–161].

Table 11
ECO4 (2008).

	R^a/P ratio (years)		
	Coal[b]	Oil[c]	Natural gas[d]
Northern	> 1000	43.8	43.4
Middle	682.2	17.9	31.9
Eastern	291.7	#	38.7
Western	> 1000	44.8	97.3
Southern	44.0	#	#
South Africa	119.6	13.6	3.0
Africa IEA	**122.7**	**37.1**	**53.3**
Europe 27	**86.7**	**7.2**	**13.8**

Authors' elaboration based on [134,135].

[a] Refers to proven recoverable reserves at end-2008.
[b] Bituminous including anthracite, sub-bituminous, and lignite.
[c] Considers crude oil, NGL and additives.
[d] Production refers to gross production net of re-injected only.

6.1.2. ECO4 Reserve-to-production ratio

Table 11 shows indicator ECO4 at the production rate and proved recoverable reserves at end of 2008 for coal, oil and natural gas.

We computed the coal reserve to production ratio (R/P) for all the sub-regions, nevertheless only for South Africa the value assumes full meaning. Indeed, as already stated, almost all the reserves and production of Africa IEA have to be attributed to South Africa: in 2008 it counted for 95.8% of the total proved recoverable reserves (31,473 million tonnes) and 98.3% of total production (256,453 thousand tonnes). The South Africa coal production chain is the only one in Africa fully developed and the R/P ratio really reflects the exploitation of the coal source. The other sub-regions report values revealing very low exploitation of the available resources that, in any case, are extremely small when compared to South Africa's value (e.g. the second largest reserves

are in Eastern Africa and they are 3.1% of South Africa reserves). Comparing Africa IEA with Europe 27, the reserves of Europe 27 are 1.7 times larger than Africa IEA, but the difference in the production is higher (2.4 times larger) and this leads to a *R*/*P* ratio for Europe 27 lower than Africa IEA.

Considering oil, there are no reserves in Eastern, Southern Africa and basically in South Africa (it counts for 0.01% of proven recoverable reserves), hence the relevant *R*/*P* values are those of Northern, Middle and Western Africa. The high value of Northern Africa reflects the large reserves (58% of total reserves) rather than a low oil production and the same occurs in Western Africa. On the contrary Middle Africa accounts for 13% of total reserves (17,342 million tonnes), but it produces 28% of the Africa IEA total production (467,609 thousand tonnes) that is the same as the production of Western Africa; therefore the R/P ratio is lower than the other sub-regions. Comparing Africa IEA with Europe 27, the reserves of Africa IEA are 11 times larger than Europe 27, but the difference in the production is lower (2.4 times larger) and this leads to a *R*/*P* ratio for Europe 27 much lower than Africa IEA.

Within the natural gas framework, Northern Africa plays the pivotal role with 58% and 72% of the total reserves and production of the continent respectively. In this case the *R*/*P* value reflects the large reserves rather than an under-exploitation of the resources. On the contrary Western Africa accounts for 35% of the total Africa IEA reserves (14,245 billion cubic meter), but it produces only 20% of Africa IEA production (267.1 billion cubic meters). This is mainly due to the lack of local demand for natural gas and the under-development of trades inside and outside the African continent. Therefore the R/P ratio of Western Africa tends to be higher than that of Northern Africa. Middle and Eastern Africa have minor impact on natural gas *R*/*P* ratio for Africa IEA, nevertheless in any case their *R*/*P* ratios arise from low production values that reflect low available reserves. Comparing Africa IEA with Europe 27, the reserves of Africa IEA are 3.4 times larger than Europe 27, but the production is similar (304.6 billion cubic meter for Europe 27 and 267.1 billion cubic meter for Africa IEA) and this leads to a *R*/*P* ratio for Europe 27 much lower than Africa IEA.

6.1.3. ECO11 Fuel shares in energy and electricity

ECO11 monitors changes in fuel shares within TPES, TFC, electricity generation and electricity installed capacity. Since the analysis of fuel share in electricity installed capacity is quite difficult due to lack of data, hereafter we focus on electricity generation, while we provided hints to the installed capacity within the previous description of the African power sector.

The trend of TPES fuel shares of Africa IEA (Fig. 12) shows that (i) the rate of growth of the natural gas supply has been the highest in the last thirty years since it reached in 2010 14% of Africa IEA TPES from 4.8% in 1980, and that (ii) the rate of growth of biofuels and waste has been the lowest since it was the one that mostly reduced the share (since 1980: −1.4% oil, −3.3% coal and peat, −5.1% biofuels and waste).

The TPES fuel shares among the African sub-regions (Fig. 13) reflect TFC fuel shares (Fig. 5), nevertheless considering the primary supplies allows to notice the contributions of (i) hydropower mainly in Middle, Eastern and Southern Africa, (ii) imported electricity in Southern Africa and (iii) nuclear in South Africa. Comparing Europe 27 and Africa IEA, the former shows more balanced source shares with larger contribution of oil (underdevelopment of the transport

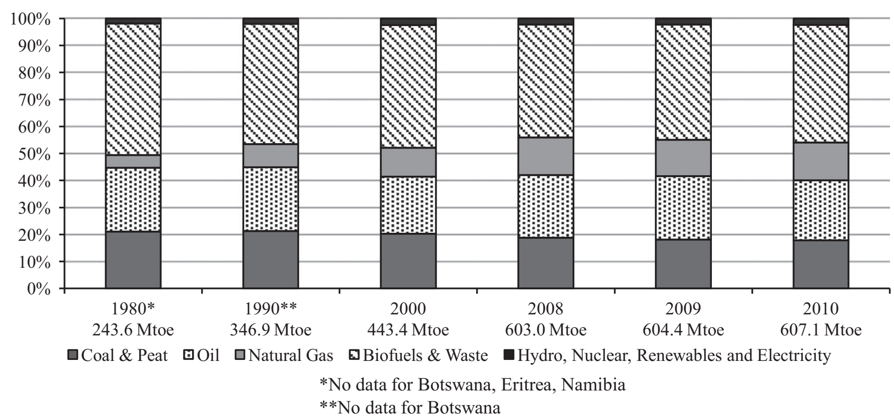

Fig. 12. TPES total values and fuels share trend for Africa IEA. Authors' elaboration based on [94].

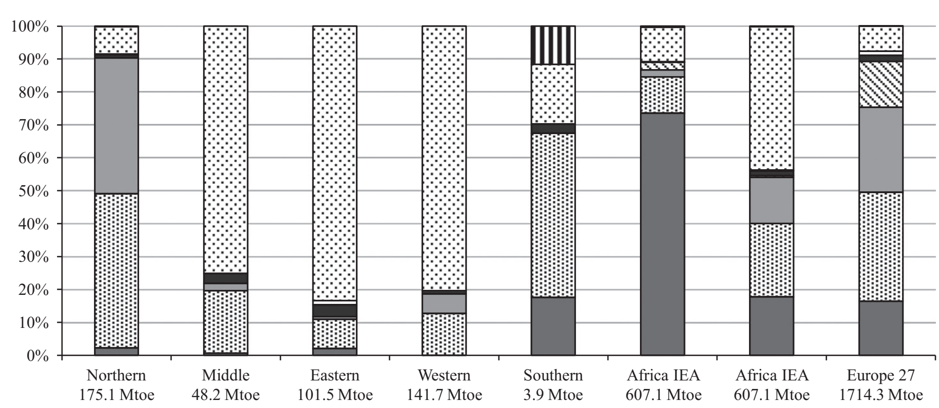

Fig. 13. TPES total values (beneath region labels) and fuel shares for African sub-regions, Africa IEA and Europe 27 (2010). Authors' elaboration based on [94].

sector in Africa IEA), natural gas (larger utilization into the power and residential sector in Europe 27) and significant contribution of the nuclear resource to the electricity generation.

TFC fuel shares trend from 1980 to 2010 can be qualitatively observed and analyzed in Fig. 4 that provides trends for the TFC and the fuels final consumptions, while the focus on sub-regions and comparison with Europe 27 for the year 2010 were provided through Fig. 5. Hence in this section we do not report further analyses on TFC beyond those previously developed.

The trend of electricity generation by fuel shares (Fig. 14) shows that the natural gas consumption increase has been mainly driven by the power sector consumption (in Northern and Western Africa). Indeed share of natural gas reached 31% of Africa IEA total generation from 14.6% in 1980. As far as coal and peat are concerned, the consumption is associated only with South Africa, but due to the increasing pace of electrification in sub-Saharan sub-regions that is mainly based on other resources, the share of coal and peat is destined to decrease. It has to be mentioned that the small percentage of renewable-based generation (0.7% of total Africa IEA) is based on geothermal power plants located in Eastern Africa (Kenyan Great Rift Valley). The focus on electricity generation by fuel shares for African sub-regions and comparison with Europe 27 for the year 2010 is provided in Fig. 6.

6.1.4. ECO15 Net energy import dependency

ECO15 refers to the ratio of total net imports (positive when net importer and negative when net exporter) to the primary energy supply when the country is net the importer or to the total production when it is the net exporter. Fig. 15 shows ECO15 for net imports of electricity, natural gas, crude oil and oil products and coal & peat. It shows also ECO15 for net imports of primary energy reported in brackets beside the sub-regions labels.

The whole continent is a net exporter and in 2010 Africa IEA exported 42% of the total primary energy produced. A quarter of coal and peat production, half of natural gas production and more than two third of production of crude oil and oil products left the continent. Electricity is imported in a very small amount in Africa IEA and it reflects the absences of interconnections among the electric power pools, this is also highlighted by the low values of imports and exports that occurred in the sub-regions.

Northern Africa exported about half of its primary energy production that resulted from exports of about half of produced natural gas and 60% of produced crude oil & oil products production. In absolute terms, it was the top exporter in Africa IEA for primary energy as well as natural gas and oil. Middle Africa exported 69% of its primary energy production that resulted basically from the exports of crude oil & oil products (91% of the production) since the imports of coal and peat, even if they are quite high as percentage of total primary supply of coal, are 0.2% of the exports of oil in terms of primary energy. Eastern Africa is the only sub-region that showed balanced import and export as for the primary energy supply. This figure resulted from large imports of crude oil and oil products that were counteracted by exports of natural gas. Moreover the absolute values of imports and exports of Eastern Africa are very low when compared with Northern or Western Africa and they reflect an energy-economy system that is based on biofuel & waste. Western Africa had a situation similar to Northern Africa; nevertheless, while exports of natural gas and crude oil & oil products were close to the Northern Africa values (in absolute terms), a higher percentage of resources left the sub-region: 87% of crude oil & oil products and 70% of natural gas

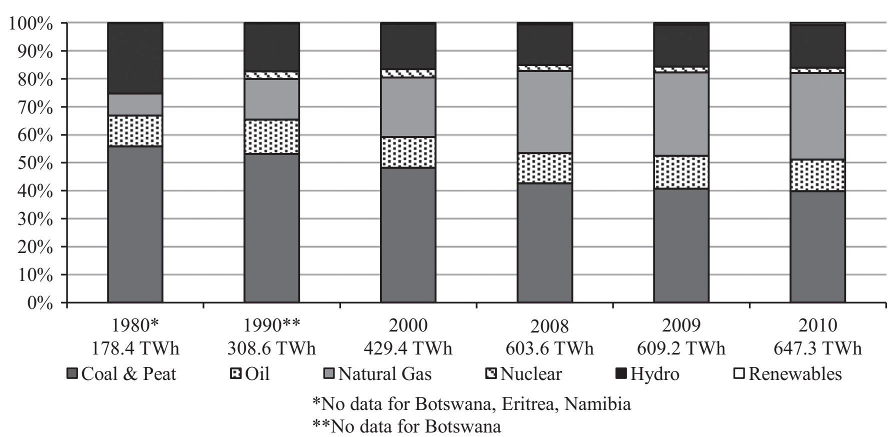

Fig. 14. Electricity generation total values and fuel share trend for Africa IEA. Authors' elaboration based on [94].

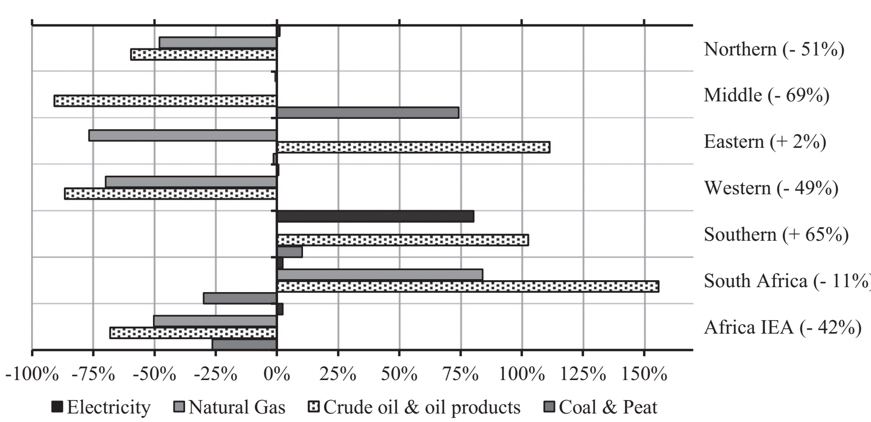

Fig. 15. ECO15: bars for Electricity, Natural gas, Crude oil and oil products and coal and Peat; values in the brackets for TPES (2010) [94].

production. Southern Africa reported very small values, in absolute terms, of import and export when compared to the other sub-regions and its economy and energy systems are strictly linked to South Africa. Indeed it was a net importer of primary energy and in particular it imported all the resources except natural gas that was not consumed within the sub-regions. South Africa exported large quantities (in absolute terms) of coal & peat that counteracted the imports of natural gas and crude oil & oil products that are not locally available. Accumulation in bunkers and stocks caused also in this case exceptional imports of oil (for this reason the indicator value is above 100%).

6.2. Household energy indicators

6.2.1. SOC1 Share of population with no access to electricity, or heavily dependent on solid fuels

With regard to data about solid fuels use, we refer to the WHO Global Health Observatory database [162] that defines *solid fuels* as traditional fuels (firewood, agricultural residues, dung, charcoal and coal) [163]. Nevertheless, only in the case of Zimbabwe, Republic of Congo, and South Africa, coal is used at household level together with traditional fuels. No disaggregated data are available to show the two components.

We calculated the two SOC1 indicators, (i) electrification (i.e. population with electric connection) and (ii) use of solid fuels (i.e. population using solid fuels), for urban and rural areas separately, in order to underline differences occurring between the two conditions (Fig. 16). We show also the total values of electrification and use of solid fuels for each sub-region and for Africa IEA.

With regard to electrification, in all African sub-regions, excluding Northern Africa and South Africa, the total rate is 51% or less, while it is less than 80% in urban areas, and less than 25% in the case of rural areas. In particular, in Eastern Africa rural electrification rate is about 7% (less than 4% in Mozambique, Tanzania and Zambia), while in Middle Africa is 6% (3.6% in the worst case of Congo D.R.). In Northern Africa, instead, total electrification rate is 89%, with a small difference between urban and rural areas, while in South Africa total rate is quite high too (76%), but the difference between urban and rural areas is large. This fact gives the evidence of an electric network not yet fully widespread.

Approximately the same qualitative considerations apply to solid fuels usage: as a matter of fact both access to electricity and to modern fuels is mainly related to the same issues, and mostly to infrastructures availability and to a sufficient income. Also in this case the difference between urban and rural access is evident, and the worst cases occur in Middle and Eastern Africa (use of solid fuels accounts for more than 60% in urban areas, and for more than 95% in rural areas). Mozambique, Togo, Tanzania and Congo D.R hold the highest values, with a use of solid fuels more than 85% in both urban and rural areas.

6.2.2. SOC3 Household energy use for each income group and corresponding fuel mix

SOC3 gives information about household energy use and fuel mix depending on the income. No data is available in international databases in order to carry out a quantitative analysis for African sub-regions, but some qualitative considerations are reported hereafter.

The relationship among household energy use, fuel mix and income has long been known, and is generally valid for all developing countries: low-income households mostly rely on firewood, agricultural residues, dung, charcoal (i.e. traditional fuels) or other traditional non-commercial fuels for cooking, and on traditional fuels, paraffin or kerosene for lighting. In middle-income households, the use of traditional fuels or similar generally accounts for about 50% of the energy needs, while kerosene or other oil products, LPG, and electricity complete the fuel mix mainly for lighting needs. As per high-income households, instead, electricity and modern fossil fuels supply most of the needs for both cooking and lighting [164]. However, it is worth noting that while the proportions between the various fuels other than traditional, and electricity, are closely related to the income, this is not always true with respect to the use of wood: according to Hiemstra and Hovorka [165], case studies across sub-Saharan Africa have revealed that firewood can be an important energy source for households at all levels of income.

In any case, for the African continent, the relationship between fuel mix and income has been confirmed by studies in some sub-Saharan countries. Mekonnen and Ko hlin [166] assessed the case of major cities in Ethiopia, while Zaku et al. [167] the case of an area in Nigeria. According to these cases 30–40% of the energy mix in low-income households is given by firewood, 20–30% by charcoal, 15–20% by kerosene, 5–20% by electricity and 0–20% by other fuels (coal, paraffin, LPG). In middle-income households, instead, firewood supplies about 20% of the needs, while 20–25% is given by charcoal, 15–25% by kerosene, 15–30% by electricity and up to 30% by other fuels. In high-income households, wood and charcoal sum up to 30%, kerosene gives 5% of the mix and electricity and other fuels give the remaining part. Campbell et al. [168] confirm the same pattern for the case of Zimbabwe. For the case of Uganda, instead, Lee [169] shows how significant differences can occur also inside the same income group between urban and rural households: firewood and kerosene are mostly used in rural areas, while charcoal and gas are more common in urban areas. Also electricity is more used in urban contexts, since the absence of infrastructures often limits its availability in remote areas. Lastly, the amount of household energy consumption is related to the income, too: low-income families use energy only for very basic needs (cooking and lighting), middle-income families use additional energy for needs such as basic appliances, refrigeration, and transport. Lastly, high-income families use fossil fuels and electricity also for cooling, ICT, etc. [164].

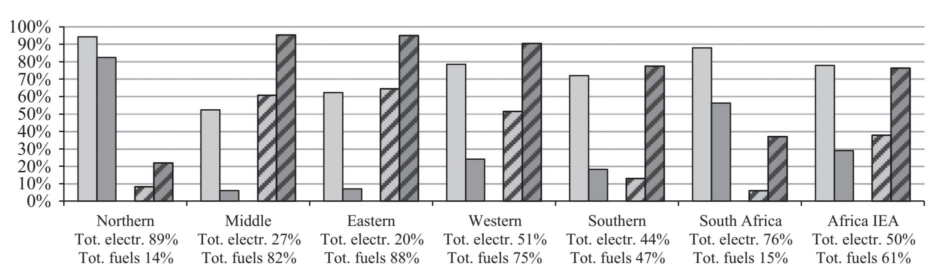

Fig. 16. SOC1 total values (beneath region labels) and for urban and rural areas (2010). Authors' elaboration based on [94–96,123,162].

6.3. Energy intensity indicators

This set of indicators groups the EISD related to the energy intensities of the different end-use sectors and the overall productivity indicator (i.e. overall sub-regions' energy intensity). Energy intensities are an important matter in the analysis of countries economic structure, hence hereafter we provide a brief introduction to this indicators.

Literature that addresses analyses of countries' energy intensity dynamics, causal factors, cross-countries comparisons, etc. is very wide (a few examples are [170–175]). According to Liddle [170], at countries' or regionals' aggregate level, four factors influence the energy intensity: (i) economic structure (the shares of energy-intensive industries in total economic output), (ii) sectorial composition of energy use (i.e. the relative shares of different end-uses like industry, buildings, and transport), (iii) fuel mix and (iv) efficiency in the conversion and end-use of energy. Furthermore factors (i), (iii) and (iv) influence the specific sectorial energy intensities. The examination of the energy intensities of African sub-regions in the light of the mentioned influencing factors goes beyond the purposes of our analysis; hence we show and compare the computed data highlighting the reasons in the main differences when possible.

6.3.1. Energy intensities of industry ECO6, transport ECO10, and sector other than industry, transport and household ECO7-8

Table 12 shows ECO6, ECO7-8 and ECO10 proxy for 2010: significant differences between Africa IEA and Europe 27 can be noticed for the energy intensity of the agriculture and service/commercial sectors (i.e. ECO7-8) and for the energy intensity of the transport sector. Considering the former, the higher value of Africa IEA compared to Europe 27 comes basically from (i) a poor agriculture value added per worker in Africa IEA (i.e. subsistence agriculture) and (ii) the underdevelopment of the service sector that, on the contrary, provides very high value added in Europe 27 [96]. Considering the transport sector, the meager consumption per capita of Africa IEA arises from the very low energy demand of this sector when compared to the population (i.e. limited amount of vehicles per capita).

The differences among the African sub-regions derive from the same (relative) differences that occur between Africa IEA and Europe 27: the sub-Saharan sub-regions (poorer than Northern, Southern Africa and South Africa) had higher values of ECO7-8 and lower values of ECO10 proxy.

Table 12
ECO6, ECO7-8 and ECO10 (2010).

	ECO6 Industrial energy intensity [toe/1000 USD_{PPP}]	ECO7-8 Energy intensity other [toe/1000 USD_{PPP}]	ECO10 proxy Energy final consumption for transport per capita [toe/pc]
Northern[a]	0.073	0.067	0.182
Middle[b]	0.069	0.313	0.04
Eastern[c]	0.159	0.379	0.021
Western[d]	0.104	0.446	0.046
Southern	0.042	0.055	0.298
South Africa	0.178	0.067	0.265
Africa IEA	**0.097**	**0.216**	**0.086**
Europe 27[e]	**0.111**	**0.048**	**0.641**

Authors' elaboration based on [94–96].
Notes for ECO6 and ECO7-8:

[a] 2008 data for Libya;
[b] 2005 data for Cameroon;
[c] 2009 data for Eritrea, no data available for Zimbabwe;
[d] 2005 data for Benin and Nigeria;
[e] 2008 data for Cyprus, no data available for Greece.

6.3.2. ECO9 Household energy intensities

Fig. 17 shows residential energy use per capita (ECO9) under the sub-region labels. On an average, at continental level, an Africa inhabitant consumed 0.29 toe in 2010, while among the sub-regions Western Africa accounted for the highest value (0.42 toe/pc) that is due mainly to the large per capita consumption of traditional fuels in Nigeria (0.535 toe/pc), while Northern Africa accounted for the lowest one (0.14 toe/pc) due to utilization of higher-efficient end-use facilities based on modern fuels.

Beside ECO9 values, Fig. 17 also highlights the shares of the energy resources in the residential TFC. Africa IEA shows very low use of modern fuels in the residential sector, that indeed is dominated by traditional fuels. Shares at continental level reflect the situation of Middle, Eastern and Western Africa that basically only rely on traditional fuels with 96%, 97% and 97% respectively. South Africa and Southern Africa have higher penetration of electricity consumption at residential level (30% and 25% respectively) than the other sub-Saharan sub-regions, but a large segment of the population still rely on traditional fuel that accounts for more than 60% of residential TFC. Modern fuels out of electricity consumption increases when considering Northern Africa where it reaches 57% of residential TFC (the maximum value in the other sub-region is 4.5% in South Africa), moreover electricity accounted for 29% of residential TFC and hence traditional fuels have the lowest value in Africa IEA (14%).

This situation arises from the following conditions: (i) large availability of natural gas and high rate of electrification which limit the consumption of traditional fuels in Northern Africa, (ii) good rate of electrification in the coal-based power system that pushes the electricity shares in South and Southern Africa. Nevertheless (iii) South Africa has large segments of the population (mainly in rural areas) that have low access to modern fuels thus leading to high consumption of traditional fuels, (iv) Middle,

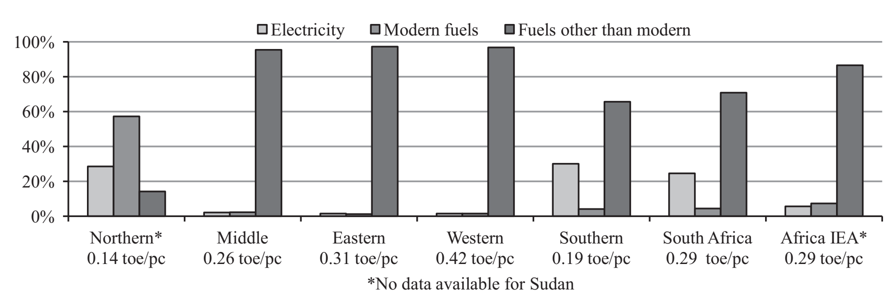

Fig. 17. ECO9 (beneath sub-region labels) and shares of consumption of electricity, modern fuels out of electricity and traditional fuels. Authors' elaboration based on [94,96,123,134].

Eastern and Western Africa have subsistence residential sectors that basically rely on the agricultural-based society, hence on traditional, locally available fuels.

6.3.3. ECO2 Energy use per unit of GDP

We computed ECO2 in terms of TPES and electricity use per unit of GDP_{PPP}. Figs. 18 and 19 show trends for Africa IEA sub-regions and Europe 27 of ECO2 as for TPES and electricity use respectively.

In both cases, ECO2 has decreased constantly in Europe 27 mainly because of (i) structural economic changes towards the service sector in spite of industries (this shift has been more significant in the eastern Europe countries) and (ii) increasing of efficiency in conversion and end-use of energy, especially in the most developed countries (i.e. the former European Union 15 block). TPES use per unit of GDP was 0.55 toe/1000USD_{PPP} in 1990 and 0.15 toe/1000USD_{PPP} in 2010 (Fig. 18), while Electricity use per unit of GDP was 718 kWh/1000USD_{PPP} in 1990 and 248 kWh/1000USD_{PPP} in 2010 (Fig. 19).

At African levels, trends depict a static situation: ECO2 decreases slowly in sub-regions as per TPES (Fig. 18), while it is almost constant (apart from South Africa and Northern Africa) as per the electricity use (Fig. 19).

Considering the TPES per unit of GDP_{PPP}, Eastern and Western Africa have the highest values mainly because (i) large part of their consumptions are absorbed by the residential sector (above 70% of the TFC) and (ii) they are the sub-regions whose economies mostly rely on agriculture. Middle Africa has a lower value than Eastern and Western Africa since, despite similar high consumption in the residential sector, it has also the most developed industrial sector in Africa in terms of contribution share to total value added [176]. South Africa is the African country with the economy most similar to European countries, nevertheless low efficiencies (coal-based power system) and the fact that large segment of the population still relies on traditional fuels have kept the energy intensity higher than Europe 27. Finally Northern and Southern Africa have the lowest share of TFC absorbed by the residential sector, while industries and services actually count for about 85% and 95% of the total value added [176], therefore their energy intensities are the smallest.

Considering the electricity use per unit of GDP_{PPP} and comparing these trends with the TPES, Eastern, Middle and Western Africa have, in this case, low values because of the very low electricity consumption (lower than 5% of TFC). The conditions of Northern and Southern Africa, that show values similar to the sub-Saharan sub-regions, do not denote a similar electricity-economic figure. On the contrary they have appreciable higher consumption of electricity and their positions compared to Europe 27 reflect the situation of the TPES per unit of GDP_{PPP}. Finally, South Africa has the highest electricity consumption in Africa and its position, like Northern and Southern Africa, reflects the situation of the TPES intensity.

6.4. Emission and pollution indicators

6.4.1. ENV1 Greenhouse gas (GHG) emissions from energy production and use

We selected the emissions per unit of GDP among the different definitions proposed for this indicator (total, per capita and per unit of GDP emissions) [84]. Moreover, we consider only carbon dioxide since no data are available for methane and nitrous oxide. Hence, in this formulation the indicator gives an idea about the carbonization of the energy system [84].

Table 13 gives ENV1 values for the year 2010. When discussing this indicator, attention should be given to several effects that can determine the final value. On the one hand, developing countries generally show small values since they use small amounts of energy in absolute terms and also because the carbon dioxide due

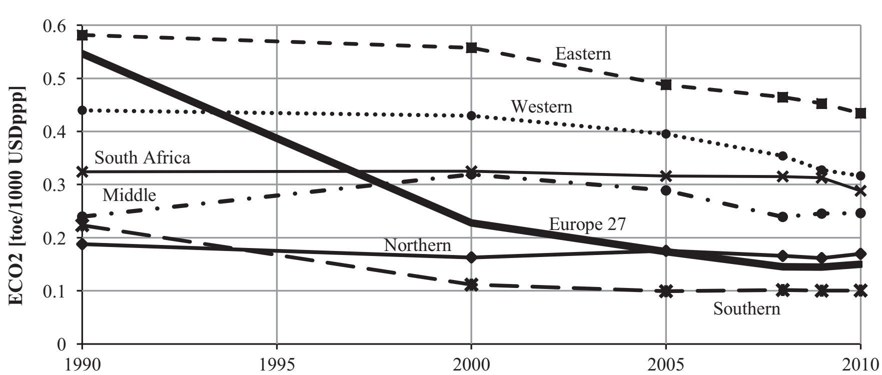

Fig. 18. ECO2 TPES per unit of GDPPPP. Authors' elaboration based on [94–96].

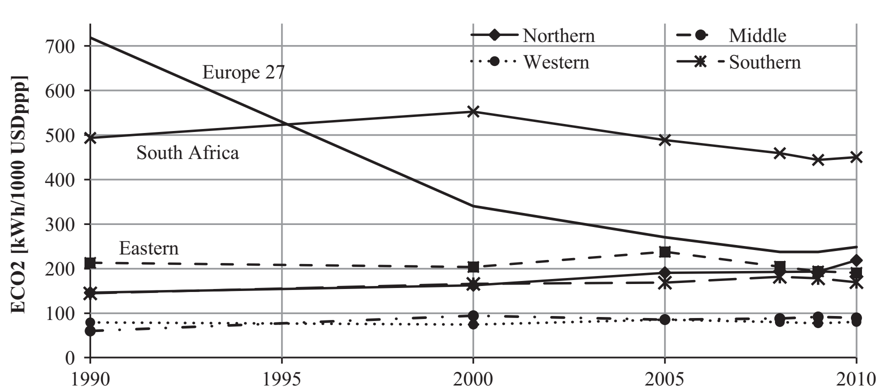

Fig. 19. ECO2 Electricity use per unit of GDPPPP. Authors' elaboration based on [94–96].

to household combustion of traditional fuels is not tracked. On the other hand, countries such as those belonging to Europe 27 have high energy consumptions in absolute terms, but also high energy conversion and end-use efficiencies. Furthermore, all other factors being equal, differences in the energy mix can have a strong influence on the emission values. Lastly, factors that influence the energy intensity, influence also the intensity of carbon dioxide emissions, as a consequence. Because of all these reasons, in some cases values of ENV1 can appear similar also in very different contexts.

Looking at each sub-region, emissions per unit of GDP of Middle, Eastern and Western Africa are the lowest in the continent: TPES per unit of GDP (ECO2, Fig. 18) is quite high in these sub-regions, but most of the energy supply is given by traditional fuels (ECO11, Fig. 13). This feature together with the underdevelopment of the industrial sector, seems to limit ENV1 values, despite the energy intensity of sectors other than industry and transports being very high (ECO6, ECO7-8, Table 12). Northern and Southern Africa have low values of almost all the energy intensities. On the other hand, their energy mix is characterized by the predominance of oil and natural gas, and oil and coal respectively: hence the carbonization of these sub-regions is higher, and ENV1 grows as a consequence. In South Africa most of the energy supply is obtained from coal, the most carbon intensive fuel. This fact, together with it being one of the most developed industrial sectors of the continent, brings the value of ENV1 up to 0.731 t/1000USDPPP. It is worth noting that the South Africa performance strongly influences the average African value, ENV1 for Africa IEA being higher than all sub-regions except South Africa itself. This gives further evidence of the huge weight that South Africa has on the statistics of the whole continent.

As per ENV1 trend (Fig. 20), a consideration is that the trend of Europe 27 has decreased during the last decades, while the African trends reflect a more static situation. In this case a clear reduction has occurred only in South Africa since 2008, due to the economic crisis (i.e. reduction in the energy consumption).

Table 13
ENV1 (2010).

	Tonnes of CO_2 per 1000 USD_{PPP}
Northern	0.363
Middle	0.148
Eastern	0.116
Western	0.162
Southern[a]	0.206
South Africa	0.731
Africa IEA[a]	**0.372**
Europe 27	**0.269**

Authors' elaboration based on [96,99].
[a] No data for Zimbabwe.

6.4.2. *ENV2 Ambient concentrations of air pollutants in urban areas*

ENV2 provides information about the air quality in urban areas by measuring ambient concentrations of air pollutants such as particulate matter, black smoke and other air pollutants. Air pollution is a critical environmental issue, that can lead to worsening of living conditions of the population and affects human health. Unfortunately, air quality has been monitored only in a few African cities, and impacts of air pollutants have been rarely assessed [177]. Hence, it was not possible to proceed with a quantitative assessment of this indicator, but we report data for some cities along with general considerations.

According to a recent review by Petkova et al. [178], some studies are available for all the African sub-regions, except Middle Africa. In Northern Africa, air pollution has been monitored in Cairo (Egypt), Algiers (Algeria), Didouche Mourad and Sfax (Tunisia), Kenitra (Morocco). In general, high or very high pollution levels emerge from the data. The major causes of air pollution are traffic and industrial activities. In most cases, also soil dust and particle re-suspension play an important role. Moreover, open waste burning contributes substantially to air pollution in Cairo, where annual PM_{10} levels can exceed 150 μg/m^3 [179,180]. In Western Africa, even higher pollution levels have been recorded in some cities, and in particular in Benin City and Lagos (Nigeria): Adeleke et al. [181] refer levels up to about 600 μg/m^3 of PM_{10} and 1170 μg/m^3 of TSP (Total Suspended Particulate) in the latter. Traffic, re-suspension and biomass burning are the three main causes of pollution [182,183]. Also in Eastern Africa pollution levels reach high values in some cities, especially in Nairobi (Kenya). The impact of smoke due to traditional fuels is confirmed. Lastly, PM10 levels up to 112 μg/m^3 have been found in urban areas in South Africa [184]. Considering the United States Environmental Protection Agency's standards for 24-h average PM_{10} and $PM_{2.5}$ concentrations, maximum values are 150 μg/m^3 and 35 μg/m^3 respectively [185]. Hence, the situation in Africa appears critical, at least for some African cities [178,186].

Behind the specific focus of ENV2 indicator on pollution in urban areas, for developing countries as well as for Africa, a more relevant issue is Indoor Air Pollution (IAP). The EISD indicators do not embrace this issue, but due to the relevance in the African context we address it in this section and within the analysis of SOC4 indicator (i.e. energy-health indicator).

The use of solid fuels for cooking and heating purposes at household level is likely to be the largest source at global scale of IAP and it represents a major environmental health burden.

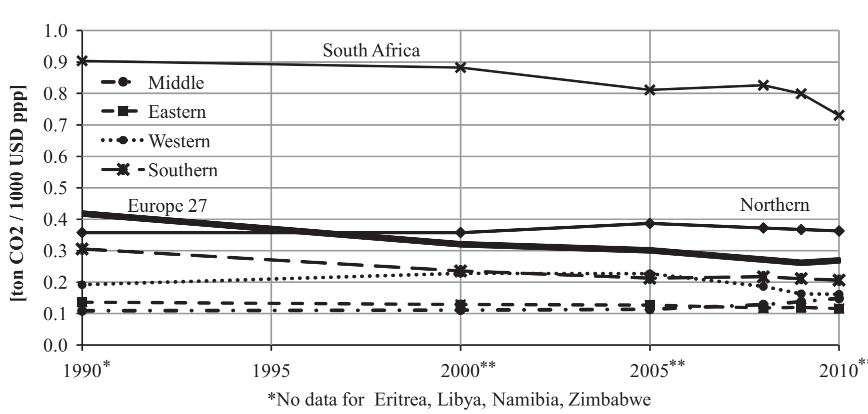

Fig. 20. ENV1 trends. Authors' elaboration based on [96,99].

Several health diseases of developing countries are related to ordinary exposure to toxic pollutants emitted by incomplete combustion of unprocessed solid fuels. Indeed, cooking and heating activities are traditionally done inside households using traditional three stone fires (i.e. open fires) and simple cooking stoves with limited ventilation. The emitted pollutants include respirable particles (PM_{10}, $PM_{2.5}$), carbon monoxide, oxides of nitrogen and sulfur, benzene, formaldehyde, 1,3-butadiene, and polyaromatic compounds [187]. Hundreds of studies have assessed levels of IAP in the developing world employing different methods (questionnaire-based, quantitative measurements, etc.). Findings of selected studies and comprehensive references can be found in [187–189]. Balakrishnan and Bruce stated in [188] that "*Lack of uniformity in methods (varying study designs and measurement protocols), small sample sizes, differences in the profiles of exposure determinants and local research capacity limitations have made it somewhat difficult to draw comparisons across studies*"; nevertheless collective evidence from these studies shows that IAP often are order of magnitude higher than national standards and WHO recommendations for indoor or even outdoor concentrations [188,190]. 24-h mean PM_{10} levels are typically in the range 300–3000 $\mu g/m^3$ and may reach 30,000 $\mu g/m^3$ or more during periods of cooking [191], to be compared with the limits previously reported. The mean 24-h levels of carbon monoxide in developing countries household are in the range 2–50 ppm, but during cooking values of 10–500 ppm have been reported. For comparison, the United States Environmental Protection Agency's 8-h average carbon monoxide standard is 9 ppm or 10 $\mu g/m^3$ [185].

6.5. Deforestation indicator

6.5.1. ENV6 Rate of deforestation attributed to energy use

ENV6 is intended to provide information about deforestation due to energy uses of biomass, that is generally intended for use as firewood (also referred to as *fuelwood*) or to be turned into charcoal. In general, deforestation is a very critical issue for the African continent: according to the latest FAO's assessment, South America and Africa had the largest net loss of forest between 2000 and 2010 (3.4 million hectares annually lost in Africa) [192]. FAO's data show that firewood accounted for about 90% of the total wood removals in Africa in 2005 (688 million cubic meters, of which 616 million cubic meters of firewood) [193]. Going into the details of each African sub-area, firewood share is in between 93% and 95% in Eastern and Middle Africa, about 86% in Northern and Western, and 40% in South Africa (no data are available for Southern Africa).

Hosonouma et al. report in a recent study [194] that firewood collection and charcoal production is the second cause of forest degradation in Africa. On the other hand, at a macro-scale level there is no clear evidence of a direct link between deforestation and the use of firewood and charcoal, particularly because most of the firewood and charcoal supply for energy needs is derived from non-forest areas such as village land, agricultural land, crop plantations, field boundaries, homestead areas and roadsides [23,195].

At the local level, instead, deforestation or, more frequently, degradation of forests and other green areas may occur or not, depending on the specific context. To give some examples, a cause–effect relationship between firewood collection and/or charcoal production, and deforestation, has been underlined by some studies in areas of Congo, Mozambique, Somalia and Senegal [75,196–198]. Firewood and charcoal are also referred to as a possible cause of deforestation in areas around urban centers in Mali, Burkina Faso, Nigeria and Niger [199]. Moreover, forest degradation due to the same causes is reported in a number of studies in different areas, such as Burkina Faso, Niger, Ghana and Togo [200–203]. Conversely, Hiemstra et al. in their review [18], come to the conclusion that in various cases firewood use is not a significant cause of deforestation, mainly due to four reasons: (i) " *while deforestation has undoubtedly occurred in many areas, some have (re)emphasized that this is mainly associated with phenomena such as agricultural growth, fire and climate change*"; (ii) "*fuelwood harvesting rarely causes long-term deforestation*"; (iii) "*negative impacts of fuelwood commercialization have been exaggerated*"; (iv) "*concerns over growing fuelwood scarcity have largely been misguided*".

In conclusion, cause–effect relationship between deforestation and forest degradation, and energy uses of biomass is a critical and unclear issue in the African continent, but surely it must be analyzed in each case by referring to the specific context.

6.6. Household energy affordability indicator

6.6.1. SOC2 Share of household income spent on fuel and electricity

The lack of data prevented us from calculating this indicator according to its definition. However, some studies about the share of household expenditure for energy needs are available in the literature: in general, according to Hammond et al., on the average low-income households use 9% of their total expenditure for their energy supply [204]. The value is in accordance with the values found per single African country: the World Energy Outlook 2002 [63] gives the share of energy expenditure in household income for Uganda and Ethiopia in 2001 (about 12% and 9% respectively), and for South Africa in 1998 (about 6%). Bacon et al., instead, report a value of about 7% in Uganda, 5% in Kenya, and 13% in Angola (2005–2006) [205], and Maliti and Mnenwa report 11% in Tanzania (2007) [206]. Lastly, a document of the African Development Bank gives an estimation of the main items of household expenditure [207]. In this case the share of housing, water and energy is given as an aggregated item. On average, the value of this aggregated share is around 14% in Africa IEA, and varies in the fairly narrow range in between 11% and 16% in the different subregions. Hence, there are no significant differences among the subregions. On the other hand, when looking at the single countries, the range widens between a minimum of 9.71% (Cameroon) and a maximum of 21.67% (Nigeria).

In general, the share of total expenditure due to energy needs decreases when the income level increases, but this pattern is not universal and depends on the context. The absolute value of the energy expenditure, instead, increases with the income level. Moreover, when looking at the geographical factor, some differences occur between urban and rural areas: in the latter, the impact of the energy expenditure is smaller. This is mainly due to the fact that in rural areas firewood collected for free is the most used fuel, while in urban areas the major difficulties in the supply (mainly the greater distance from areas where firewood is collected) leads to a greater use of purchased firewood, charcoal or other solid fuels [205,208].

Lastly, it is worth noting that, even if the absolute expenditure increases with the income, when considering commercial fuels the average cost of an energy unit can be much higher in the case of low-income households than in high-income ones. In addition to this, the average cost of an energy unit for households in remote rural areas is higher than the cost of an energy unit in an urban area [209]. This is clearly due to the use of different energy resources, and mostly to the use and availability of electricity that substitutes paraffin, kerosene or other fuels for lighting: households using kerosene can pay up to 70 times more than households using electricity from the grid, and those using batteries can pay up to 30 times more [208,210,211].

Table 14
Key pollutants due to solid fuels combustion and related potential health effect.
Source [191].

Pollutant	Potential health effect
Particles (PM_{10}, $PM_{2.5}$)	• Wheezing, exacerbation of asthma • Respiratory infections • Chronic bronchitis and chronic obstructive pulmonary disease • Exacerbation of chronic obstructive pulmonary disease
Carbon monoxide	• Low birth weight (fetal carboxyhaemoglobin 2–10% or higher) • Increase in perinatal deaths
Polycyclic aromatic hydrocarbons	• Lung cancer • Cancer of mouth, nasopharynx and larynx
Nitrogen dioxide	• Wheezing and exacerbation of asthma • Respiratory infections • Reduced lung function in children
Sulphur dioxide	• Wheezing and exacerbation of asthma • Exacerbation of chronic obstructive pulmonary disease, cardiovascular disease
Biomass smoke condensates including polycyclic aromatics and metal ions	• Cataract

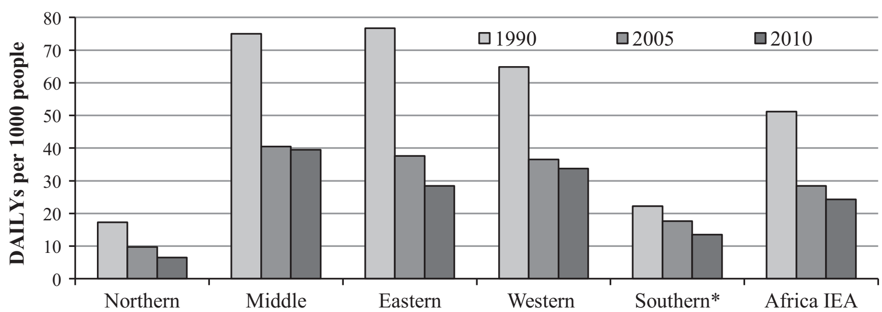

Fig. 21. DALYs due to IAP in Africa. Author's elaboration based on [216].

6.7. *Household energy-health indicator*

As previously stated, in the developing world health diseases due to Indoor Air Pollution (IAP) caused by the large use of traditional biomass for energy needs are a very important issue. Globally, the common cited figure is of 1.6 million premature deaths annually for use of solid fuels, second only to tobacco smoke as an environmental risk and tenth largest risk overall [212,213]. International organizations (i.e. WHO) and academia have been addressing this issue since the early '80s focusing the research activities on relating pollutant typologies, concentrations and health effects. Table 14 summarizes key pollutants in household smoke and related potential health effects.

When looking at the top-five causes of death in sub-Saharan Africa, respiratory infections occupy the third place, accounting for about 10% of total deaths, after HIV/AIDS and malaria (respectively about 20% and 10%), followed by diarrheal diseases and perinatal conditions [214]. To give evidence of this fact, a proxy for SOC4 at the household level was computed as DALYs per 1000 people due to household IAP resulting from solid fuels combustion. According to the WHO's definition, DALYs (Disability Adjusted Life Years) are computed as the sum of the years of potential life lost due to premature mortality and the years of productive life lost due to disability caused by one or more selected issues [215]. We computed DALYs due to all causes related to household IAP from solid fuels as available from IHME databases [216], i.e. influenza, respiratory infections, trachea, bronchus and lung cancers, ischemic heart disease, cardiovascular diseases, chronic obstructive pulmonary disease and cataracts.

The bar graph in Fig. 21 shows data for each African sub-region. South Africa has been included in Southern Africa since only aggregated data are available. The significant decrease of DALYs between 1990 and 2010, especially in Middle, Eastern and Western Africa, is a positive figure. On the other hand, in these areas DALYs remain much higher than in Northern Africa, with values in-between 29 and 40 DALYs for every 1000 people. This situation reflects the considerations previously made for SOC1. In particular, acute respiratory infection mainly affects women and children exposed to IAP, making them the main victims of the indoor use of solid fuels [190,217,218]. Moreover, IAP from solid fuel use increases the risk of other conditions related to children not accounted for in the IHME estimations, such as low birth weight and stillbirth [219,220].

7. Energy policies and action plans overview

As investigated in previous sections, Africa sub-regions differ even consistently in the resources disposal and utilization. Such differences bring about different sets of challenges [221] which have lead in Africa to an evident pluralism of actors involved in the energy sector through several policies and action plans [222]. Governmental agencies and international organizations, development banks and funds, power utilities associations, NGOs and

others, undertake actions addressing energy-related challenges. The fragmentation of the policies and action plans and the lack of harmonization represent one of the main key points. In fact the actors involved in this frame have priorities and roles that often differ or even overlap.

In the light of this situation, the purpose of this section is to summarize and highlight the main policies and action plans that African entities have set and are intended to be pursued in the future. Despite the high commitments, international actors such as UNDP, UNIDO, UNDCF, the European Development Fund, the European Union Energy Initiative, or The World Bank are not included in this review since our focus is to depict policies proposed by players operating only in the African context which in the future, with proper coordination and clear definition of roles, could act as leaders in continental or regional directives development. The analyzed documentations address policies and action plans specifically tailored to the energy sector and do not consider energy-related policies and action plans when resulting from policies that address other sectors (e.g. the transport sector). In particular the review considers and analyzes: (i) continental institutions, i.e. the African Union, its sub-agency NEPAD and the PIDA program; (ii) a governmental actor, i.e. the Forum of Energy Ministers of Africa (FEMA); (iii) a development fund entity, i.e. the African Development Bank group; (iv) the African regional economic communities, i.e. CEMAC, ECOWAS, EAC, SADC, AMU and (v) other stakeholders committed with planning and integration of specific regional action plans. Finally we present a short overview of the European Commission approach towards energy policies in order to provide a possible reference for Africa in managing the energy issue at multinational level.

7.1. Continental institutions

The African Union (AU) was established in 2002 and is composed of 53 African States. Working with regional and continental institutions, the African Union aims at promoting regional cooperation in Africa, strengthening political and socio-economic integration, joining common interests among countries and fostering a process of democracy, good governance and human rights [222,223]. The commitment of AU in the energy sector has been present for many years, and the creation of the NEPAD Agency (New Partnership for Africa's Development) represents the actuation of this involvement. NEPAD Agency was established in 2001 and was integrated as a technical body of the African Union in 2010. NEPAD acts under the paradigm to facilitate and coordinate regional and continental integration, and promote interdependence. It has worked in strict cooperation with continental partners and actors of the energy sector: from the institutional side (e.g. the Forum of Energy Minister of Africa), to the union of private power companies (e.g. UPDEA) [223]. Moreover it has also been involved in the development and operationalization of the regional power pools. In the Agenda set in 2001 [224], NEPAD put forward a development strategy whose energy sector priorities were resumed with the following objectives:

- to increase from 10% to 35% or more, access to reliable and affordable commercial energy supply by Africa's population in 20 years;
- to improve the reliability as well as lower the cost of energy supply for productive activities in order to enable economic growth of 6% per annum;
- to reverse environmental degradation associated with the use of traditional fuels in rural areas;
- to exploit and develop the hydropower potential of river basins of Africa;
- to integrate transmission grids and gas pipelines so as to facilitate cross-border energy flows;
- to reform and harmonize petroleum regulations and legislation in the continent.

A recent and effective implementation of the AU/NEPAD strategy has been defined in the Program on Infrastructure Development in Africa (PIDA), where the master plan for the activities in the energy sector and for regional integration in infrastructure is detailed [225,226]. The implementation of PIDA has joined the complementarity of roles of several actors: (i) NEPAD in coordinating the implementation and facilitating the strategies harmonization, (ii) financial institutions (e.g. African Development Bank) in financing and providing technical support for project preparation and capacity building actions, (iii) member states, utilities and regional bodies in leading the execution phases through project financing and monitoring [227]. Before PIDA and at a level of action plan, AU and NEPAD in 2010 endorsed the African Action Plan (AAP) which sets a list of priorities for the African energy sector to 2015. The specified energy-related goals have been directed in promoting intra-African trade, use of clean energy, regional cooperation, global exports and efficiency in infrastructure [223]. Nevertheless the more updated action plan is the Priority Action Plan (PAP), which refers to the PIDA and combines previous Short-Term Actions: the NEPAD Short-Term Action Plan and the infrastructure component of the AAP. The PAP aim is to define a detailed and immediate program on regional integration and a cross-border market development to be pursued by 2020. It was approved in 2012 by the African Heads of State and it would mobilize a total budget of 360 billion USD mostly dedicated to energy and transport projects. Indeed a PAP objective is to guarantee access to electricity to more than 60% to any African Country by 2040 [225]. In order to address this objective one component of PAP consists in 15 energy projects that amount to a budget of 40.3 billion USD. These projects include: nine hydro power plants, four transmission corridors, and two pipelines (one for oil and one for natural gas) [225].

7.2. Governmental actor: the Forum of Energy Ministers of Africa

On institutional level, committees composed of Ministries of Government have represented important channels to energy strategies development. The committees serve as common platform where energy interventions are linked to other infrastructural interventions, coordinating in this way energy development to a more wide extent [1]. Furthermore by coordinating local, national and international programs, economies of scale and reduction of costs are realized and higher impacts are obtained than interventions held by single countries in isolated and individualistic actions [221,228].

The Forum of Energy Ministers of Africa (FEMA) proposed specific targets in line with addressed NEPAD strategies. As specified in [229], FEMA suggested a set of objectives acknowledging the role that modern energy plays in achieving the Millennium Development Goals (MDGs). Even though not included in the MDGs, FEMA recognizes energy as the major multiplier of the goals, principal mover for eradicating poverty, providing services and sustaining economic growth. The path towards the achievement of MDGs includes the following points:

- doubling of the consumption of modern fuels including increased energy access for productive uses. The use of modern biomass for industrial purposes should be explored.
- 50% of inhabitants in rural areas should use modern energy for cooking. Options should include improved cooking stoves, use of pressurized kerosene stoves and LPG stoves.
- 75% of the poor in urban and peri-urban areas should have access to modern energy services for basic needs.

- 75% of schools, clinics and community centers should have access to electricity.
- motive power for productive uses should be made available in all rural areas.

7.3. Fund agencies: the African Development Bank group

The African Development Bank Group was established in 1964 aiming at the promotion of economic and social development in Africa. The Group is committed to provide grants, loans and assistance to the Regional Member Countries and to support governmental or private actors in their investments. The Group includes the African Development Bank (AfDB), the African Development Fund (ADF) and the Nigeria Trust Fund (NTF) [222]. In the last 40 years, the Bank Group assigned around 12% of funds to energy, 90% of which to power supply. Large-scale power generation projects were mainly supported, followed by fossil fuels projects (refined petroleum products and gas), power transmission and distribution, multi-national grid interconnection and rural electrification [230]. In 2008 the AfDB approved the Clean Energy Investment Framework, with the strategic goal of eradicating poverty conditions and constituting leverage for the development of different sectors: from household to social service institutions, from industries and business entities to infrastructure facilities. Objectives set to 2030 were the following, as reported in [230]:

- accelerating the reduction of energy poverty and vulnerability, by increasing access of households and small economic operators to reliable and affordable energy supplies;
- facilitating sustained high rates of economic growth, by providing operators in the productive sectors with realistically priced electric power and energy supplies;
- contributing to world-wide energy security, by sustaining significant exports of energy resources to the rest of the world, while increasing African countries' collective self-sufficiency and strengthening regional inter-dependence in energy services and products;
- promoting clean development and contributing to global emissions reduction efforts, by steadily raising energy efficiency on the supply side and encouraging a culture of energy saving on the demand side, increasing the contribution of renewable energy resources, and paying close attention to environmental and social externalities of energy production.

The AfDB has also recently endorsed a Climate Change Action Plan (CCAP) for 2011–2015, which is based on three main aspects: Low Carbon Development, Climate Resilient Development and Funding Platform. The goal is to strengthen African countries in their ability to adapt to climate change and mobilize fund resources [231]. Priority in the intervention is given to projects that foster climate-resilient development, also supporting low-carbon actions aiming at enhancing the GHG mitigation potential. The major targets related to low carbon development are [231]:

- clean energy and energy efficiency providing advisory services and financing for supporting initiatives up to 5 GW worth of clean energies or energy efficiencies;
- sustainable transport, with multi-modal transport infrastructure, mass rapid transit systems and railway transport;
- increasing the area under sustainable forestry management, reducing rate of deforestation and forest degradation, providing sustainable source of fuel wood for rural households;
- improving agricultural and land management, where ecosystems and biodiversity are preserved properly.

7.4. Regional actors

7.4.1. Communauté Économique et Monétaire de l'Afrique Centrale (CEMAC)

The Economic and Monetary Community of Central Africa (CEMAC) is an organization of Central African states, whose mission is to promote peace and development of member states, enforcing the establishment of the Economic Union and Monetary Union. The activities of the community aim at strengthening the cooperation among members and the process for economic integration [232]. Countries in the region established a Central African Power Pool (CAPP), as specialized agency of the power sector, under the NEPAD Program in 2003. In 2006, CEMAC adopted a plan of action for the years 2008–2011, with high focus on hydropower. However these initiatives are yet to materialize [233]. The action plan may be divided in three main issues (access to electricity, access to domestic fuel and political actions) and consists on the following activities [234]:

- energy planning in line with rural and peri-urban demand;
- coordinated development of hydropower;
- rational use of surplus biomass waste from agro-industrial units in rural and peri-urban areas;
- rural energy service projects in the promotion zones;
- intensive peri-urban electrification project;
- promotion of photovoltaic;
- optimizing the domestic fuel market;
- support for the coordinated development of the hydrocarbon market;
- elaboration of an energy charter in the CEMAC zone;
- establishment of an energy access observatory in the CEMAC zone;
- technology transfer and strengthening of national value added.

The action plan has laid down the goal of 50% of energy access which has been declined in the following actions: (i) supplying 50% of the peri-urban population via the power grid, (ii) providing individual power supplies to 35% of rural households (grid or solar kits), and installing a corresponding infrastructure in non-electrified villages, giving 56% of rural inhabitants access to power supplies. Another challenging goal consisted of improving domestic fuel services in up to 80% of peri-urban and rural areas by 2015. The implementation has been followed combining different means: diffusion of GPL in peri-urban areas and secondary towns (accounting for 44%) and utilization by other households of improved stoves with chimney exhausts (accounting for 36%).

7.4.2. East African Community (EAC)

The East African Community is a regional inter-governmental organization that entered into force in July 2000 [235]. From the beginning energy development has been a priority in EAC policies. As stated in article 101 of EAC treaty [236], efficient exploitation of resources, promotion of renewable resources, interconnections and pipelines have been endorsed. Moreover, in order to meet the MDGs, EAC launched a process based on three programs: the Regional Development Strategy (2006–2010), the East African Power Master plan and the Regional Strategy on Scaling up Access to Modern Energy Services. This process aims at guaranteeing reliability of supply and access to modern energy on regional basis, strengthening industrial and agriculture development. Four strategic targets have been endorsed [237]:

- use of modern fuels for cooking by half of the population which currently bases cooking services on traditional biomass;
- access to reliable electricity for all urban and peri-urban poor;

- provision of modern energy services (such as lighting, refrigeration, information and communication technology) and water treatment and supply for all schools, clinics, hospitals and community centers;
- access to mechanical power within all communities for productive uses.

The recent 4th Development Strategy, approved in November 2011, follows this direction and sets different objectives for the time period from 2011/12 to 2015/16. Some objectives are at institutional and strategic level: promoting the strategy on scaling up access to modern energy services, harmonizing energy policies, preparing the energy sectorial master plan, and establishing the EACPP (EAC Power Pool). Some others refer to the effective implementation of infrastructure development: cross borders interconnections, oil pipeline and regional shared energy projects [235].

7.4.3. Economic Community of the West African States (ECOWAS)

The Economic Community of the West African States was founded in 1975 and it includes 15 nations [238]. Activities tailored to the energy sector mainly aim at promoting integration among the countries and supporting the design and implementation of technical projects in the region [222]. In 2000, ECOWAS also established the West Africa Power Pool (WAPP) to enhance electricity trade, to increase investments in the ECOWAS community and to decrease the electricity prices. In 2006 ECOWAS endorsed a White Paper, where member states and the region have been involved in a comprehensive policy to increase access to modern energy services. The goal of the White Paper is to provide by 2015 access to modern energy services, increasing four-fold the situation in 2005. As reported in [239], member states shall target by 2015:

- 100% of the total populations (or 325 million people) should have access to a modern cooking fuel;
- at least 60% of people living in rural areas should have access to productive energy services in villages, in particular motive power to boost the productivity of economic activities;
- 66% of the population (or 214 million people) should have access to an individual electricity supply that should result by providing access to electricity for 100% of urban and peri-urban areas and 36% of rural populations.

Moreover by 2015, 60% of the rural population should live in localities (i) with modernized basic social services, (ii) with access to lighting, audiovisual and telecommunications service, and (iii) with decentralized power generation installations as solutions for the isolated contexts. The implementation of the program is endorsed by ECOWAS keeping into consideration the strategic and general guidelines indicated by PIDA. Indeed, in April 2013 ECOWAS ministers met in Yamoussoukro, Cote d'Ivoire, to discuss in the framework of the PIDA Priority Action Plan, the way to align it in the national plans and to give acceleration to the implementation of the plan [240].

7.4.4. Southern African Development Community (SADC)

The Southern African Development Community is an intergovernmental organization which originates from the Southern African Development Coordination Conference, established in 1980. It includes 14 countries and aims at promoting socio-economic, political, security cooperation and integration among the member states [222]. During the SADC Heads of State and Governments meeting in 2001, strategies and targets to tackle poverty were defined and, concerning the energy sector, six main targets, with different time bound, were listed:

- establishment and strengthening of private sector regional associations such as the Petroleum and Gas Association, and regional associations of regulators such as the Regional Electricity Regulatory Association by 2004;
- establishment of energy data banks and planning networks by 2005;
- harmonization of energy sector policies, legislation, rules, regulations and standards by 2006 to facilitate energy market integration;
- identification and strengthening centers of excellence for energy research and technology development by 2008;
- to achieve 100% connectivity to the regional power grid for all Member States by 2012;
- to achieve access to modern forms of energy supplies to 70% of rural communities by 2018.

In the electricity sector the strategies aim at promoting the extension of grid interconnections to encompass all member countries and at upgrading the existing ones. Moreover the intention was to create an electricity market where countries belonging to SAPP (Southern African Power Pool) may have a competitive position. Concerning the hydrocarbon resources, the program endorsed joint exploration, development of resources and policies' actions to foster cross border trade, increase capacity utilization and cooperate in joint procurement of petroleum products. Some cross cutting issues were also faced, in particular to improve access to affordable energy services to rural communities through electrification and through the development of renewable energy resources. At institutional level research and technology development, efficient use of information and empowerment of people will be strengthened [241].

The recent SADC Regional Infrastructure Development Master Plan (RIDMP) was approved in August 2012. As part of the PIDA, the RIDMP has been supported at continental level by the African Union [241]. The Energy Sector Plan depicts four energy security areas: (i) improving access to modern energy services, (ii) tapping the abundant energy resources, (iii) up-scaling financial investment and (iv) enhancing environmental sustainability [242]. In detail, the project listed in the plan comprises 89 infrastructures, divided into power generation, regional interconnections and storage facilities [243].

7.4.5. Arab Maghreb Union (AMU)

The Arab Maghreb Union was formally instituted in 1989 and included the five Maghreb states: Algeria, Libya, Mauritania, Morocco and Tunisia. The signed agreement aimed at guaranteeing cooperation, enforcing dialogue and interdependence, contributing to give strategic relevance to the region. However, within this Union, interaction has never been really effective and for the entire period few joint actions have been promoted [244]. After a period of stagnation, in July 2008 AMU energy ministers renewed the intention to cooperate together and officially agreed on a plan for the development of renewable energy resources and nuclear energy use in the region [245]. As mentioned in [223], AMU has identified the Maghreb Renewable Energy Programme among its priorities, confirming the prominent role that member states have been addressing to the renewable technologies.

Despite the recent renewed commitment of the Union, no defined energy strategies have been identified. However, an effective actuation of joint action in this region may be represented by the Comité Maghrébin de l'Electricité (COMELEC). It gathers enterprises responsible for production, transportation

and distribution of electricity among the five countries of Maghreb and aims at developing initiatives and coordinating projects of common interest [246]. COMELEC strategies have been mainly oriented toward the creation of an integrated transmission system, with a non-discriminatory and transparent access for Maghreb members, strengthening the interdependence and creating a common and harmonized legislative and regulatory framework [247]. All these initiatives are also tailored to comply with requirements needed for cross-border electricity trade [248], strongly endorsed by the North countries and the European Union, which recognize the high potential of Maghreb in the exploitation of renewable resources, as also demonstrated by initiatives like Desertec [249] or the Mediterranean Solar Plan [250].

7.5. Other stakeholders

The process of fostering the energy sector through the regions has to include institutional actors, at continental and regional level, whose support is a necessary precondition to prepare the correct policy framework. However, private or non-profit actors may also have an essential role, for example to ensure that coordination with energy companies is in place. To this kind of actors belongs UPDEA (Union de Producteurs, Transporteurs et Distributeurs d'Energies électrique d'Afrique) that is a no-profit organization gathering African power generation utilities as well as foreign organizations involved in the continental power sector [251]. While UPDEA was established in 1970 with headquarters in Côte d'Ivoire, a more recent association (originated by the members of UPDEA) is APUA (Association of Power Utilities of Africa), founded in 2012. This new association represents an actual response to the current situation of the African power sector and whose mission is "*to bring together Power Utilities and Stakeholders towards making power more accessible, affordable and reliable for African people*" [252]. The planned activities for 2012–2014 are based on four pillars. The first one encounters the capacity building of member companies and the support in funding activities, with actions that address training, dissemination of good governance and social responsibility, sharing best practice and organizing meetings and forums. The second one is related to energy efficiency and renewable energy, to strengthen creativity and innovation among stakeholders, encouraging research and development in the power sector. The third one is on rural electrification and South-South cooperation, aiming at promoting integration, mobilizing funds and strengthening partnership among companies. Finally the last pillar is on strategic level, focusing on the role that the new association APUA has and leads in relation to the power pools [253].

7.6. The energy policies of the European Commission at a glance: a possible reference for Africa

The lack of a defined shared strategy and the fragmentation among the African countries have contributed for the last decades to the difficulty to overcome the energy deficit in the continent and to enable a favorable ground towards the access to sustainable energy. Due to a different historical, geographical and political situation, the European Union constitutes an effective example of coordinated energy policy development where strategies, plans and actions are depicted at a higher level by the Union and single countries are called to define and implement them.

Within the European Union, energy policies are formulated through European legislation as directives, regulations and decisions. They follow some political principles (i.e. subsidiarity, proportionality and better regulation), as explained in the Union Treaties, which consider that member states are ultimately responsible for their national energy mix and that indigenous energy resources are not European, but national. Based on these lines, proposals are prepared on the basis of wide stakeholder consultations, with national and regional bodies, industrial and consumers associations, individual companies and non-governmental organizations [254]. The importance of energy as strategic sector and the necessity of coordinated actions among the European countries were raised after the Second World War and continued in the following decades, when countries put in place first coordinated initiatives to address the security of the community supply [255,256]. Especially from the '90s, programs were adopted at European level and began to highlight the concern on the coupling energy consumption-environment [257,258]. This led after the 2000 to define a common frame on strategic issues as energy security and climate change, also following the ratification of Kyoto Protocol in 2002. European energy policy principles were then explicitly defined in 2007 as the core of an action plan [259], which included three key principles (sustainability, security of supply and competitiveness [260]) and the quantification of the 20/20/20 targets.

In the European energy policy development, renewable energies have been recognized as a means to achieve these principles. Since the last decades the commitment and support of several Member States and the Commission has provided a relevant progress in the renewable energies sector, which has been confirmed by the most recent Directive 2009/28/EC. This Directive sets out a framework for the use of renewable sources in order to limit greenhouse gas emissions and to promote cleaner transport. The framework addresses pathways for the development of cooperation mechanisms to help in effectively achieving the targeted cost and establishes the sustainability criteria for biofuels [261]. Energy efficiency is another pillar and is part of the 2020 targets and of several policies and directives [262]. Moreover, efficiency has been recently promoted in the Energy Efficiency Plan in 2011 [263] and in the Directive 2012/27/EU [264].

Efforts are currently addressing a series of directives aiming at the promotion of an effective and more competitive internal energy market, in national policies and lack of energy interconnections. This process of harmonization requires an urgent refocusing on infrastructure, common accounting rules and a shared approach to capacity markets and renewables trading [265]. Moreover, the pathway towards a more coordinated body will enforce the role of the European Union in the world energy frame, in the Mediterranean region and with the main international suppliers [260], it will provide competitiveness, ensure safety and guarantee a higher commitment on the climate change.

8. Coupling energy assessment with policies overview

Hereafter we analyze the energy situation and policies in the light of the EISD framework. Purposes of the analysis are to summarize the main issues of the energy situation and to identify the policies and action plans that address such issues highlighting direct and indirect targeted indicators. With this aim we identify the linkages among the selected EISD indicators taking into account both indications provided by IAEA, and the unique picture of African countries. We also refer, as baseline, to the indicators analysis carried out by Streimikiene [86,87]. The result of the analysis is depicted by the scheme in Fig. 22 where the cause-effect linkages between the groups of indicators are pointed by the arrows and relevant policies are shown for each group.

As is shown in the scheme, reading from left to right, the *Energy sector indicators* and *Household energy indicators* are contributing factors for those included in the Energy intensity group. Moreover, the indicators of the Energy intensity group are identified as core indicators since they act as a proxy of the overall

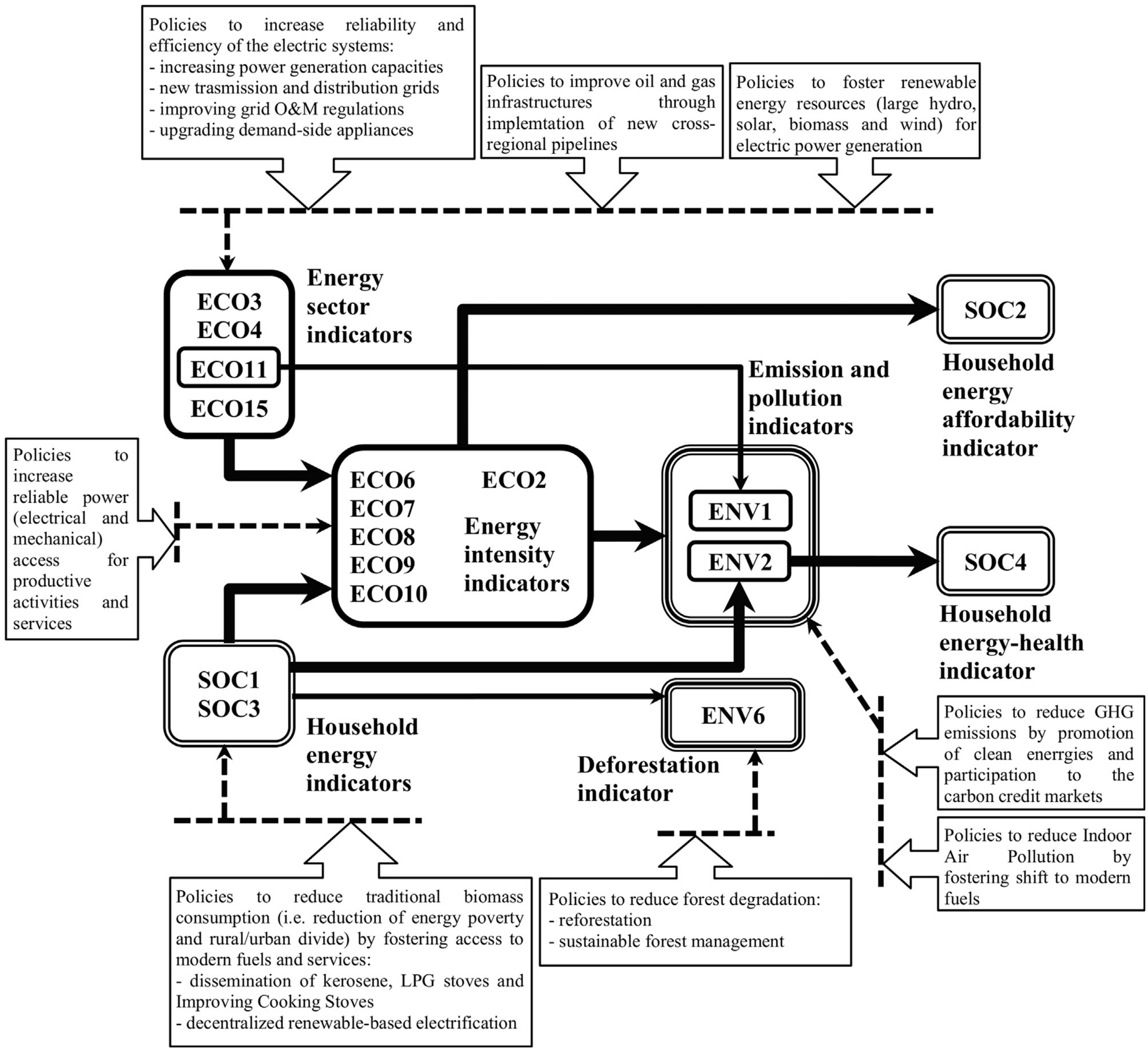

Fig. 22. Linkages between selected indicators, and relevant policies based on targeted indicators.

economic-energy efficiency of a country or a region. The *Emission and pollution indicators* are a consequence of the overall economic-energy efficiency, while specifically the GHG emissions (ENV1) are influenced directly by the energy mix (ECO11), and the indoor pollution (a component of ENV2) is a consequence of the type of energy systems used at the household level (*Household energy indicators*). It is also evident, in the African context, that issues addressed by *Household energy indicators* may also contribute to deforestation (ENV6). Finally, the *Household energy affordability indicator* is related to *Energy intensity indicators,* and the *Household energy-health indicator* is a consequence of *Emission and pollution indicators* and particularly of ENV2.

Here below, we carry out the analysis by coupling the energy situation and policies following the EISD indicators groups as defined in Table 9.

8.1. *Energy sector analysis*

The power infrastructure is affected by a low level of reliability of the supply as well as low efficiencies in transmission and distribution (ECO3). Moreover these issues are exacerbated by the absence of interconnections among the sub-region electric power pools (ECO15) and high values of non-technical losses (i.e. mainly illegal connections).

Strategies to ensure reliability mainly have two modalities of intervention: (i) increase of power generation capacities, and (ii) construction and upgrade of transmission grids. One effective example of the first strategy is the PIDA Priority Action Plan, undertaken by NEPAD, where the construction of nine projects of hydropower plants is defined as priorities to be pursued by 2020. The same endorsement has been taken by the AfDB, whose Clean Energy Investment Framework clearly sets a target by 2015 on effective installed power generation capacity. New power plants usually result in having an installed capacity that exceeds the local needs since they are often located far from urban areas and since economies of scale push towards large size installations. Therefore power plants projects have often regional or sub-regional dimensions and involve several countries. As a consequence cross-countries transmission systems are endorsed with the result of improving the overall reliability of the network towards sub-regional balance between supply and demand. Transmission corridor projects are detailed in the PIDA Priority Action Plan,

where the path towards a cross-integration and the actuation of a plan for regional exchanges is evident.

Strategies tackle inefficiencies in the energy systems at different level and with a diversified paradigm of interventions. African Union has put as strategic objective in the PIDA the promotion of efficiency in the energy infrastructure sector through new power plants installation and new transmission interconnections. The AfDB has also put the energy efficiency as one of the main actions in the Low Carbon Development pillar. The Bank has defined as indicative target an increase of 5% in supply-side technical efficiency gains by 2015, and a further increase to 20% by 2020. These goals may be achieved acting on infrastructures, through appropriate energy policies that motivate operators to upgrade generation, transmission and distribution systems and improving the O&M regulations with effective measures. On the contrary and besides large infrastructures projects, FEMA has identified interventions at household level as solutions for increasing efficiency, e.g. introduction of more efficient cooking devices, fuel substitution programs, use of improved stoves, and more efficient charcoal production methods. On a similar pattern regional actors have promoted efficiency intervention at community level, endorsing plans that put as a priority the shift to modern fuels.

Proven recoverable reserves of fossil fuels (coal, oil and natural gas) are always relevant in Africa even when compared with the other world regions. Moreover they are located in specific subregions (ECO4, ECO15): coal reserves are in South Africa, oil reserves are mainly in Northern Africa and Western Africa (i.e. Nigeria and Angola), and natural gas reserves are mainly in Northern Africa and Nigeria.

The relevance of fossil fuel resources and particularly of the hydrocarbon picture is evident. Facing this situation, in the NEPAD Agenda of 2001 the necessity to reform the petroleum regulation and legislation was raised. However, investigated policies and plans have not shown a specific focus on this sector: generally they have turned more attention to the hydrocarbon sector in the connecting infrastructures like oil and gas pipelines (e.g. in the PIDA Priority Action Plan), rather than to the oil and gas exploration and production. At regional level only SADC has specifically faced the fossil fuel sector, as it can be highlighted in the Regional Indicative Strategic Development Plan. The Plan has endorsed actions that aim at a coordinated intervention in the region: for instance joint regional exploration and improvement of capacity utilization were sustained as well as the cooperation in joint procurement of petroleum products from the world market.

Large shares of the produced primary energy are exported; indeed Africa is a net energy exporter of all the primary resources (coal, oil, natural gas) and hence of primary energy (ECO15).

In order to sustain the export market and, on a wider frame, to accelerate the regional integration of the continent, policies have clearly shown an effective endorsement of infrastructure implementation of oil and gas pipelines. In the PIDA Priority Action Plan, two pipeline projects are listed: (i) the Uganda–Kenya Petroleum Products Pipelines, 300 km long pipeline, crossing Uganda and Kenya, already in the implementation/operation phase in March 2012, and (ii) the Nigeria–Algeria Gas Pipeline, 4100 km long pipeline, crossing Nigeria, Niger, Algeria, in the phase of feasibility/needs assessment in March 2012. On a longer term, two other projects are endorsed by the NEPAD to be implemented by 2040: the Tanzania–Kenya Pipeline and the South Africa–Mozambique Pipeline. Through these interventions, export rate will be increased promoting in this way the utilization of resources in new exploited and remote areas. The AfDB, in line with these actions, has endorsed the role of the African continent in supporting the world energy security and set the indicative target of net positive energy exports to the rest of the world throughout the period 2008–2030.

At the moment the contribution of renewable energies (other than hydropower) to electricity generation, in Africa is negligible. However Renewable potentials in electricity generation are huge and it can be reasonably stated that they could provide significant contribution in increasing electricity supply (Table 6).

The role of renewable resources is recognized to have higher importance, especially within clean energy policy frameworks. As highlighted by different strategies and plans (e.g. NEPAD, PIDA), the selection of technologies has seen a predominance of large hydropower installations. Moreover each regional community has transposed continental directives into plans tailored to the specific context and put the renewable energies as a distinctive pillar of the future energy mix. ECOWAS, in its White Paper, defined the target of 20% of new investments in electricity generation driven by local and renewable resources, aiming at achieving energy self-sufficiency, reducing vulnerability and promoting sustainable environmental development. In the Regional Indicative Strategic Development Plan, SADC set as priority strategy to endorse by 2018 the development of renewable energy resources, including solar, biomass and wind generated energy. On a similar framework, CEMAC defined as priority the access to predominantly renewable-based electricity supplies, while EAC has been sustaining the shift to an increasing renewable capacity through the implementation of large hydropower installations. It is worth nothing that no explicit endorsement or programs on geothermal energy have been declared despite the high potential in the Rift Valley region.

8.2. Household energy analysis

Biofuel & waste (i.e. traditional biomass) covers the largest share of Africa TPES as well as TFC, and specifically it is the energy resource used to meet the main energy needs in the residential sector (i.e. cooking and heating). The TFC trend shows how its consumption continuously rises driven by the population growth, while the penetration of modern fuels shows more moderate growth. A clear gap exists among Middle, Eastern and Western Africa, and Northern, Southern and South Africa: biofuels & waste accounts for most of the TPES in the first group, while the second group mostly relies on other fuels (ECO11). Moreover the analysis of SOC1 highlights the issue of the rural/urban divide: except for Northern Africa, the difference in access to electricity and modern fuels is huge, with rural areas that lag far behind urban areas.

The issues of traditional biomass consumption have been faced by institutions at different levels, both continental and regional, and the use of modern energy as instrument for improving living conditions has been clearly recognized. In the strategic objectives of PIDA, the use of clean and modern energy to reduce biomass consumption has been marked and constituted a priority for the development of the energy sector between 2010 and 2015. The AfDB clearly set as final objective by 2030 the reduction of energy poverty among households, having as an expected result the access to reliable supplies including refined fuels (kerosene, petrol, diesel, biofuels or gas). The prominent role of the utilization of modern energy has also been endorsed at governmental level, as reported by FEMA. The importance of the shift to higher efficiency biomass stoves (Improved Cooking Stoves), or through a shift to modern fuels like kerosene or LPG has been highlighted. At regional level, organisms have endorsed the same commitment. ECOWAS defined as objective by 2015 the provision for all population of modern or improved cooking services, by access to modern fuel and to Improved Cooking Stoves and with a sustainable supply of biomass. CEMAC intends to face the issue by setting the target by 2015 to reduce up to 80% of traditional fuels in rural and urban areas, achievable for instance through LPG and Improved Cooking Stoves dissemination. SADC encountered a

similar target and defined the target of 70% of modern energy supply by 2018. EAC has also defined in its strategy the necessity of shifting to modern forms of fuel, endorsing the change of 25% of people currently using traditional biomass.

Addressing the issues of access to electricity and rural/urban divide, decentralized renewable–based strategies have also been proposed. AfDB, in the Climate Change Action Plan, set as expected result by 2015 the development of renewable solutions in rural areas, including hydro, geothermal, wind, solar, biogas, and the promotion of decentralized mini-grids.

8.3. *Energy intensity analysis*

The analysis of the energy intensity indicators (ECO2, ECO6, ECO7-8, ECO9, ECO10 proxy) shows poor levels of energy intensity, in general and for all sectors, compared with the European values. This is mainly due to a low agriculture value added and the underdevelopment of the service, industry and transport sectors. Differences among the sub-regions occur, but the development of all sectors is particularly low in all sub-Saharan sub-regions.

The analyzed policies have shown a high attention towards the reliable power access for productive activities. NEPAD declared that reliability and affordable cost of the supply are essential prerequisite to enable economic growth. At governmental level, ministries of FEMA recognized the role that energy access have in triggering business opportunities and set as energy target the diffusion of mechanical power for productive uses in all rural areas. At regional level, the economic communities have transposed in their specific energy agendas for this issue: EAC has undertaken the goal of guaranteeing access to mechanical power within all communities for productive uses, while ECOWAS has set a share of 60% of people of rural areas with access to productive energy services. Clean Energy Investment Framework of AfDB has also sustained the goal of providing access to reliable energy supplies to operators and business establishments that produce more than 75% of GDP. The Framework addresses sectors such as agriculture, resource extraction, processing industries, manufacturing, services and set the targets in almost all of categories of 100% of access to electricity by 2015. Furthermore strategies and plans have also been oriented to provide energy for community services, contributing to the development on a wider range, through an improvement of the welfare systems. Indeed, several actors have included in their targets the provision of energy to meet community needs in schools, clinics and hospitals. FEMA set the goal of access to electricity in 75% of schools, clinics and community centers, EAC aimed at the provision of modern energy services and water treatment and supply for all schools, clinics, hospitals and community centers, ECOWAS set the target of 60% of the rural population with access to modernized basic social services.

8.4. *Emission and pollution analysis*

Oil is used in all sub-regions due to the transport sector demand, while natural gas and coal play a significant role in the energy mix of specific sub-regions. Natural gas is mainly used in Northern and Western Africa, while coal is consumed almost totally only by South Africa (ECO11). Hence, the high level of carbonization of the African energy system (ENV1) is a consequence of the high shares of fossil fuels such as coal and oil, together with the poor efficiencies of the system.

In the Energy Investment Framework of AfDB, the renewable energy contribution related to the issues of carbonization and pollution is clearly underlined. Indeed, the promotion of clean energy becomes part of the objective of 2030 that aims at contributing to the international climate mitigation efforts: targets are set for GHG emissions, carbon intensity of economic activities and livelihood. Moreover the participation to the international carbon credit markets through Clean Development Projects is endorsed.

8.5. *Deforestation analysis*

As a general issue, a direct link between deforestation and the use of biomass is not fully assessed. However the qualitative analysis of ENV6 shows how deforestation and, more commonly, forest degradation can occur at the local level due to the use of firewood and charcoal, strictly depending on the local context.

The analyzed policies encompass in their objectives the environmental problem of forest degradation. In certain cases they address the issue as a direct consequence of the exploitation of traditional fuel resources (for instance NEPAD); in others they stress the necessity to enhance the environmental sustainability in terms of land and forest management. The AfDB, in the Climate Change Action Plan, highlighted the necessity of increasing the area under sustainable management measures: it set as indicative target a reduction of 2% in the current rate of deforestation and land degradation by 2015, achievable through methods of afforestation and reforestation. Furthermore this goal is connected with the supply of sustainable fuel wood for rural communities.

8.6. *Household energy-health analysis*

Use of biomass is one of the three main causes of air pollution in African urban areas, together with traffic and particle resuspension (ENV2). Industrial activities significantly contribute to the problem mainly in Northern Africa. Air pollution in African cities should be addressed as a critical issue, since pollution levels can reach extremely high values. The combustion of solid fuels is also the main cause of Indoor Air Pollution (IAP), which causes an ordinary exposure to toxic pollutants, since cooking and heating activities are traditionally done inside households using three stone fires or simple cooking stoves. IAP is mainly responsible for the spread of respiratory infections and other diseases in the continent: DALYs per 1000 people due to IAP resulting from solid fuels combustion are very high in sub-Saharan Africa, affecting in particular women and children (SOC4).

Institutional actors as FEMA have recognized the relevance of this issue and clearly undertaken the commitment to work jointly to tackle it. FEMA intended to face the problem of IAP by setting the target of 50% of communities in rural and peri-urban areas that have to shift to modern cooking fuels by 2015. This objective represents an essential prerequisite for tackling specifically the issues of child mortality and maternal health.

9. Conclusions

The paper aims at depicting an up to date assessment of the energy situation in Africa. We employ a set of quantitative indicators to provide a comprehensive understanding of primary and electric energy supply as well as resource potential and fuel mix, and we compute a number of EISD to show the Africa energy situation as regards sustainable energy development. A review of the policies and action plans by some of the most relevant players in Africa is also given with the goal of clarifying whether these policies are somehow related with the needs and the main issues that have risen from the quantitative evaluation.

An interesting framework for connecting the EISD indicators highlighting the cause–effect linkages between some of them is also given as one of the main achievements of the paper. Policies are then related within this framework and a combined analysis is

finally carried out. Even if this analysis is carried out ex-post, a positive element comes out since it emerges that there is a general match between the quantitative evaluation and the policies that are promoted by different players. Nevertheless a fragmentation of policies and a lack of coordination with other connected open problems still represent one of the most critical elements: energy is strictly related to environment, water, food security and land management and thus a major coordination in the policies promoted in these fields should be a must.

Whatever the specific and detailed directions that the incoming Sustainable Development Goals and the post 2015 agenda for development will promote [266], a general agreement on the need of integration is shared at the global level. To this very relevant consideration, the achievement of our paper suggests an additional element: the need of ex-ante, in itinere and ex-post analysis based on a wise combination of quantitative metrics (data analysis) and more common qualitative evaluations (social perception). The joint cooperation between technical scientists and policy makers could then contribute to support the assessment, the implementation and finally the revision of appropriate policies for integrated resource management able to effectively promote sustainable development at the local and global level.

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